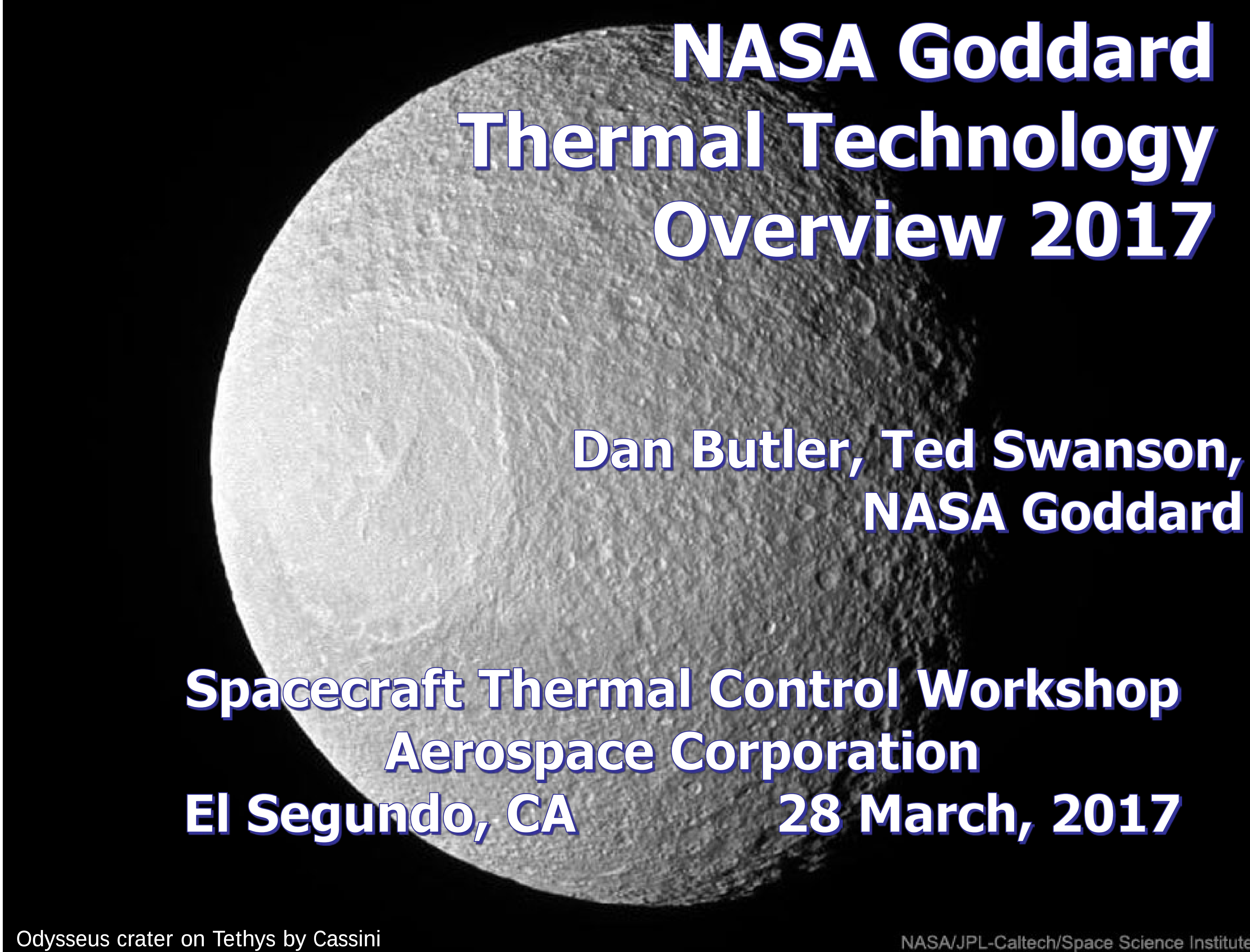
NASA Goddard Thermal Technology Overview 2017

Dan Butler, Ted Swanson,
NASA Goddard

Spacecraft Thermal Control Workshop
Aerospace Corporation
El Segundo, CA 28 March, 2017



Odysseus crater on Tethys by Cassini

NASA/JPL-Caltech/Space Science Institute

FY17: Where is the budget going?

- **The trend is on hold!** **FY14** - $17.65B, **FY15** - $18.01B, **FY16 - $19.28B,** **FY17** – continuing resolution until late April at least

- **NASA FY16 Budget Enacted** (in millions of dollars)
  - SCIENCE $5,589.4
  - SPACE TECHNOLOGY $686.5
  - AERONAUTICS $640.0
  - EXPLORATION $4,030.0
  - SPACE OPERATIONS $5,029.2
  - SAFETY, SECURITY, AND MISSION SERVICES $2,768.6
  - OTHER $541.3
  - **TOTAL $19,285.0**

- **President's FY17 Request: $19.025B** ($283M less than FY16 enacted)

Notes on Budget

- Some of the biggest winners in the FY16 budget are: planetary science, the exploration program (including the Space Launch System and Orion), and commercial crew
  - For now, this continues
- Most observers expect no major changes in FY17; awaiting President's FY18 budget request for first real indication of future direction.
  - February 3rd: Acting Administrator, Robert Lightfoot, says there have not yet been any major changes to NASA programs
  - Michael Freilich, head of Earth Sciences Division, says he does not expect major changes to his program for the rest of the fiscal year.
- NASA transition team reportedly well integrated at NASA HQ. Includes previous senior NASA managers (e.g., Chris Shank, Shana Dale, and others).
- Lamar Smith, Chair of House Science Committee, expects NASA *Authorization* bill to pass soon

What else is happening regarding technology?

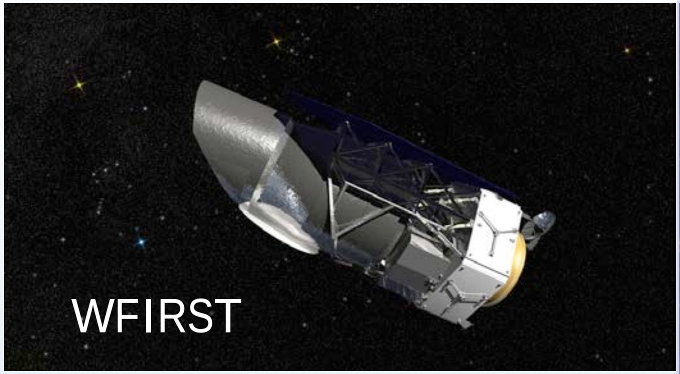
- New set of **Technology Roadmaps** continues to be referenced by many NASA solicitations.
  - Thermal technology reportedly faired well in recent funding review.

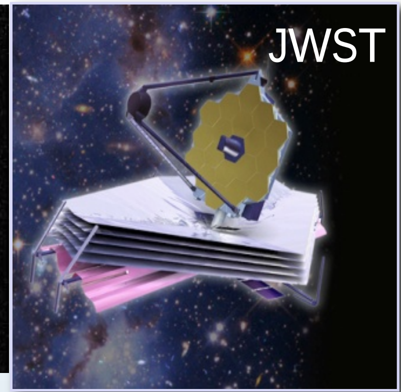
    http://www.nasa.gov/offices/oct/home/roadmaps/index.html

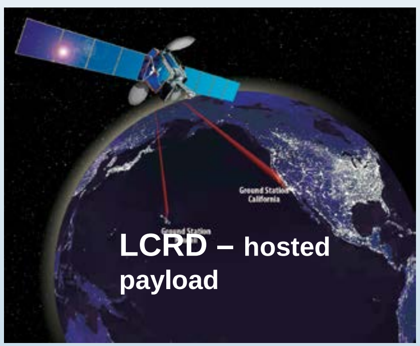
- **TechPort** – continues to mature as a database for technology developments
  - Detailed information on individual technology programs and projects
  - Allows extensive search capability and sharing of information

    http://techport.nasa.gov

NASA GSFC Future Missions

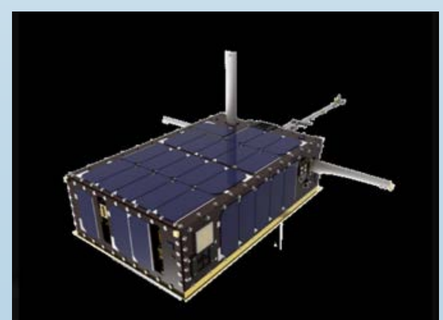


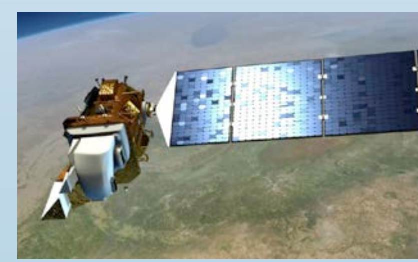




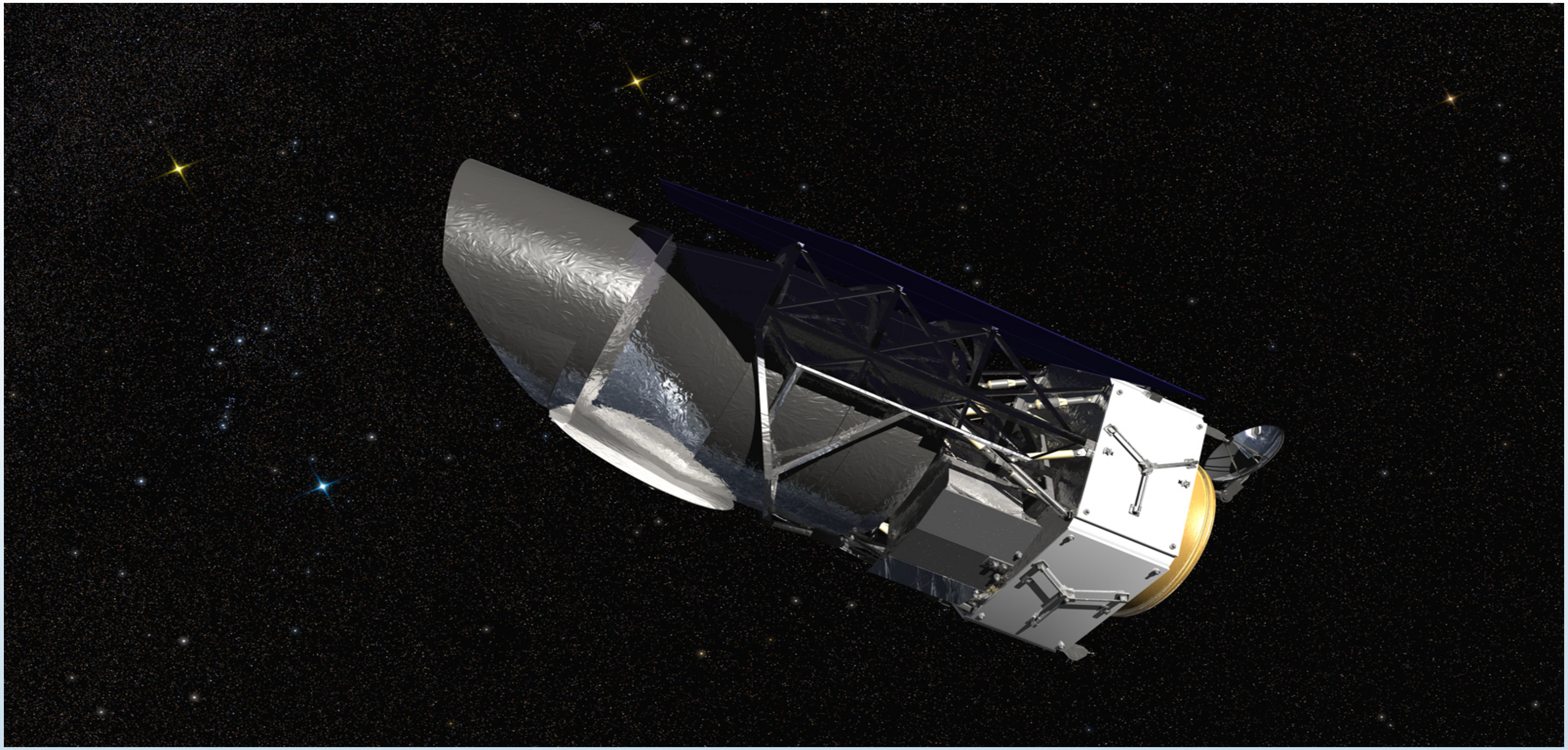

GOES-R


JPSS


CUBE-SATS


Landsat 9

WFIRST – launch in mid-2020's



WFIRST will carry a Wide Field Instrument to capture Hubble-quality images enabling cosmic evolution studies. Its Coronagraph Instrument will directly image exoplanets and study their atmospheres. Uses "Hubble-like" spare telescope gift from another agency.

May have advanced Creare cryocooler similar to Hubble NICMOS cryocooler, and cryogenic heat pipes

JWST primary mirror segments assembled in the GSFC clean room

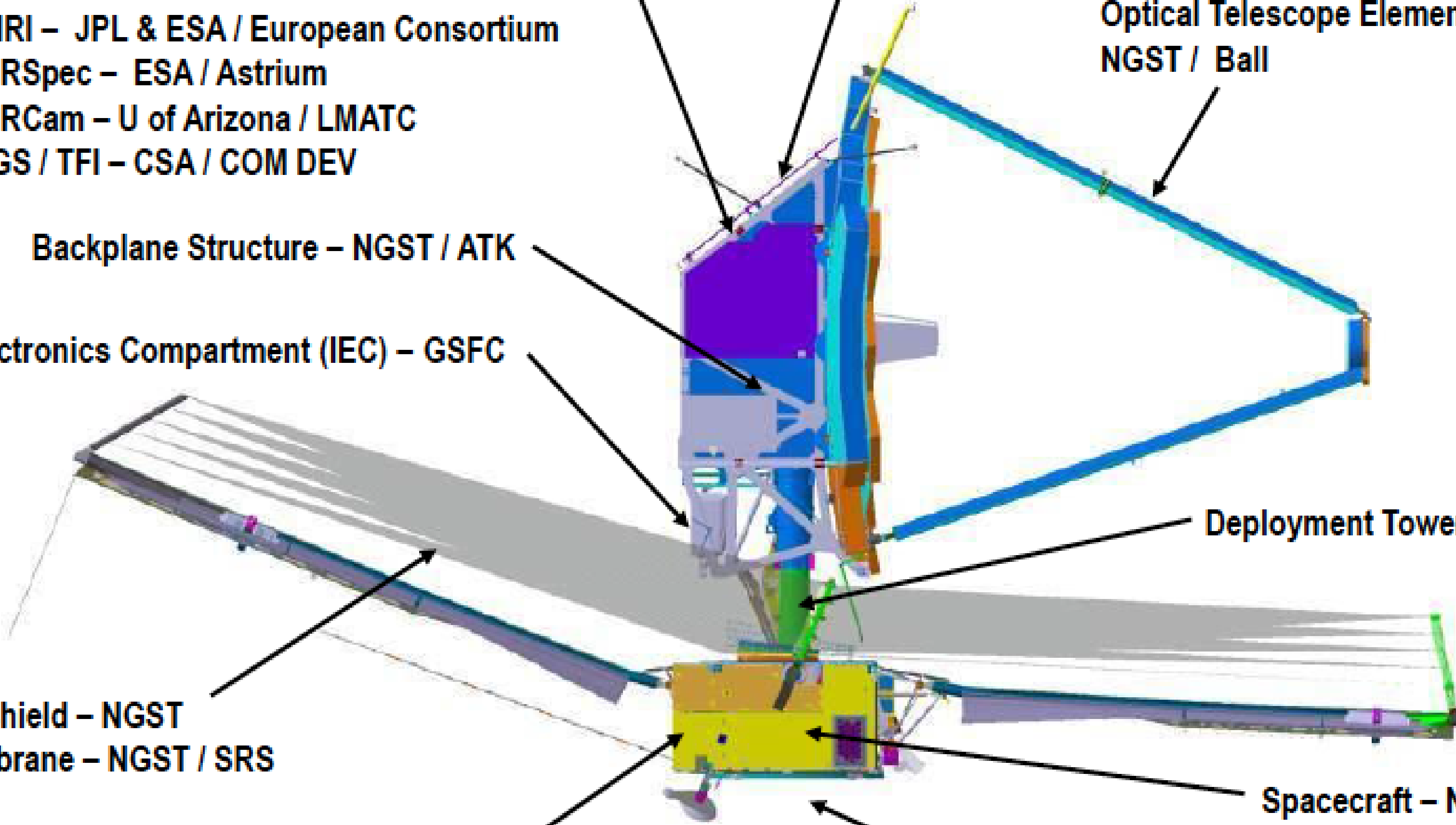
Instrument Thermal Vacuum testing completed at GSFC– 3 tests 24/7 over 3 months long each

“Core” TV test complete at GSFC – verified interface between warm Spacecraft and cold instruments and mirror assembly. Retest required due to issue with MLI.

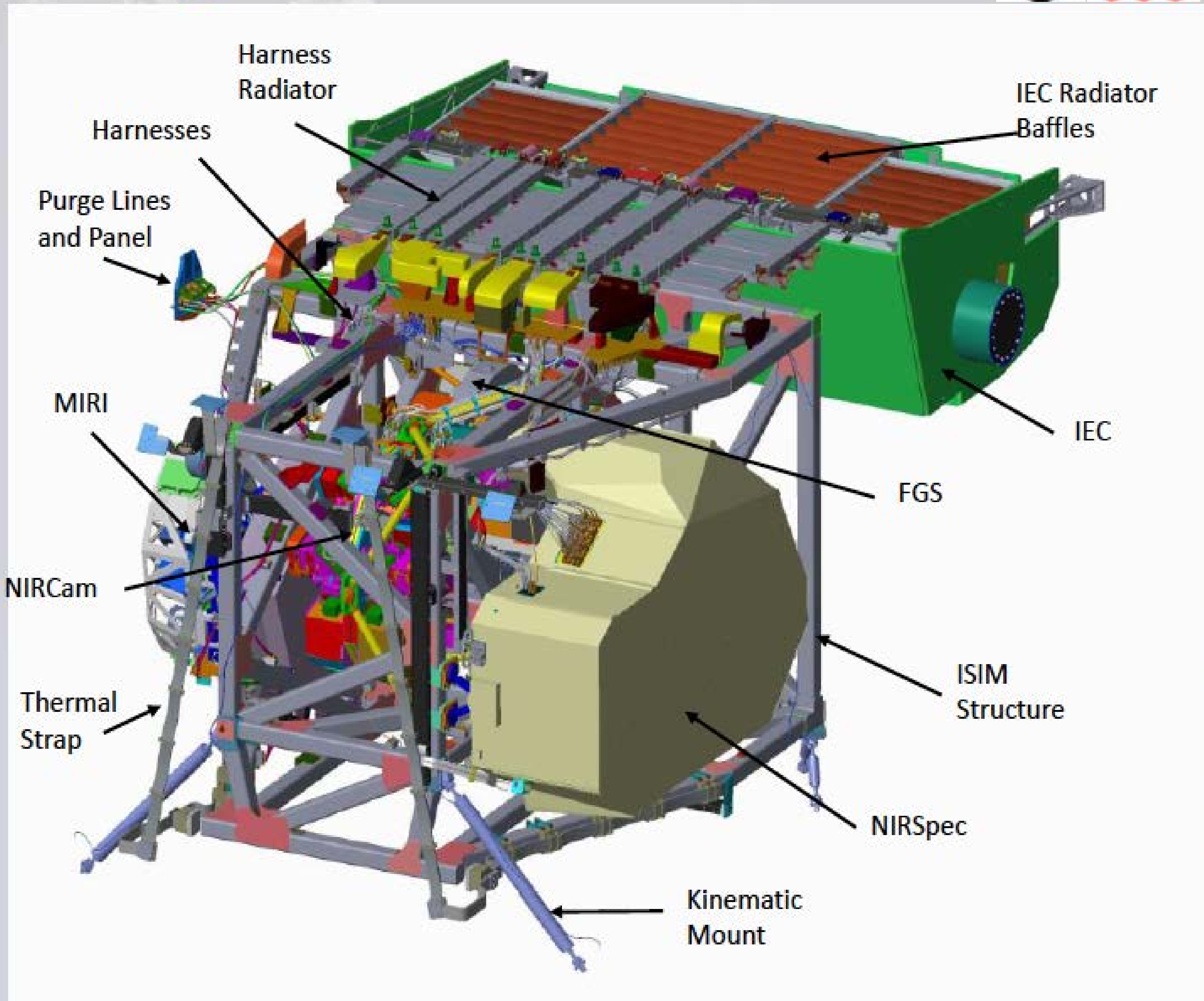
TV test of GSE and Chamber A certification with Helium shroud completed at JSC

Test of integrated Mirror and instrument assembly in Chamber A at JSC later this year. There is NO test of all up S/C, sunshield, mirror, and instruments.

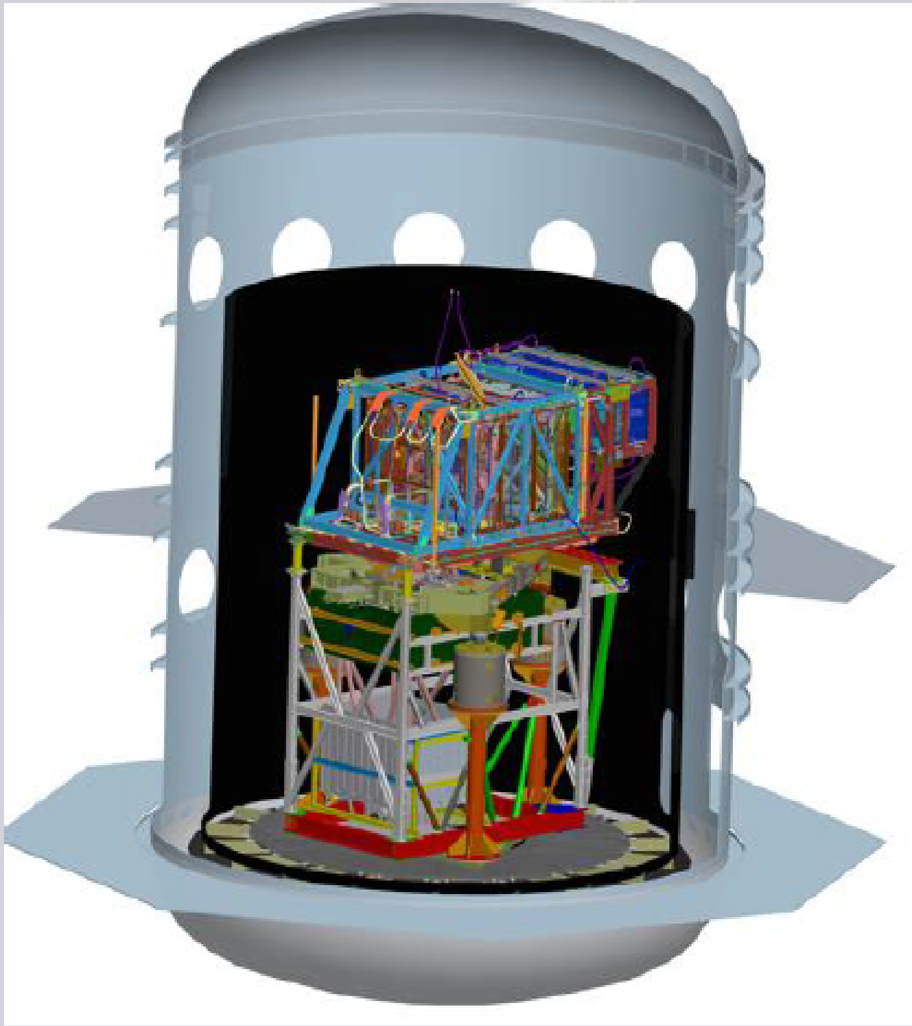
James Webb Space Telescope



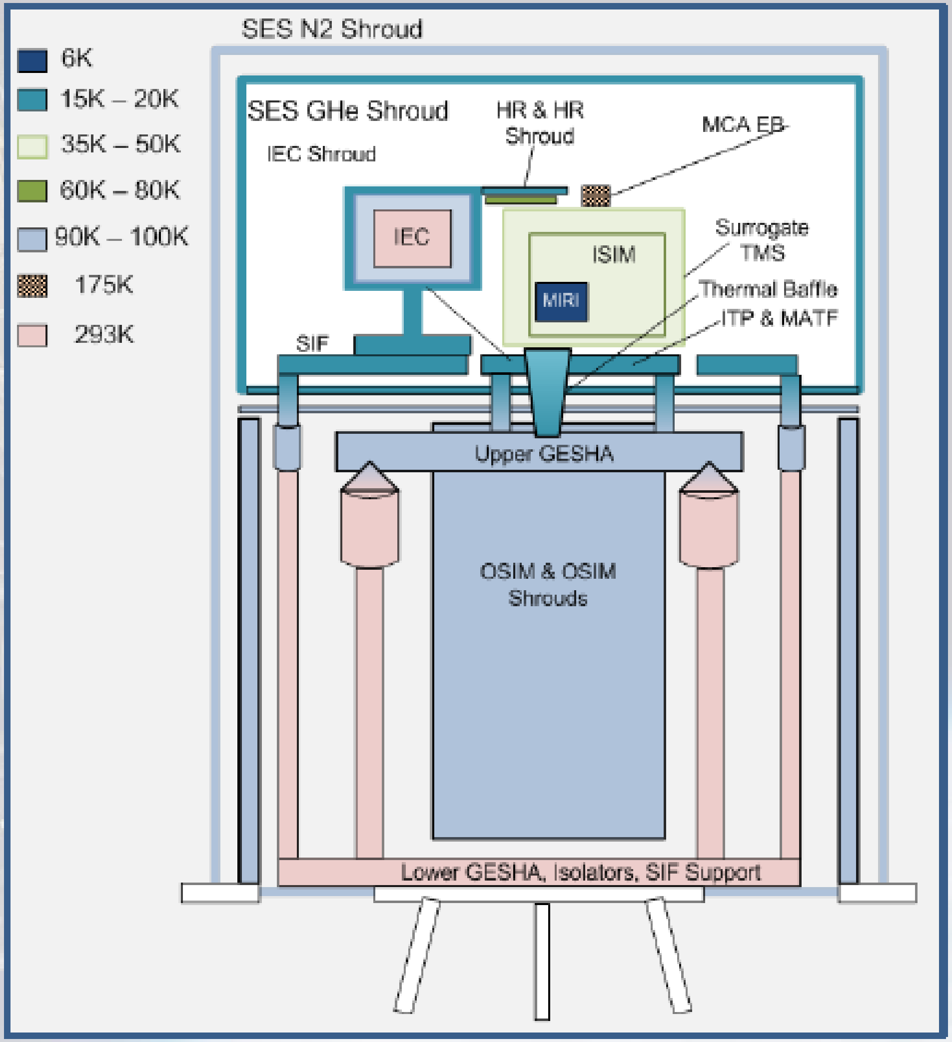
Major Design Elements of the ISIM



ISIM CV Test Configuration: Overview



ISIM Payload, GSE, Plus Optical Simulator (OSIM), inside GSFC 8.2m dia., 12.2 m tall Space Environmental Simulator (SES)



General Temperature Ranges Held in ISIM Cryo-Vacuum Testing

ISIM CV Test Special Equipment: Q-meter

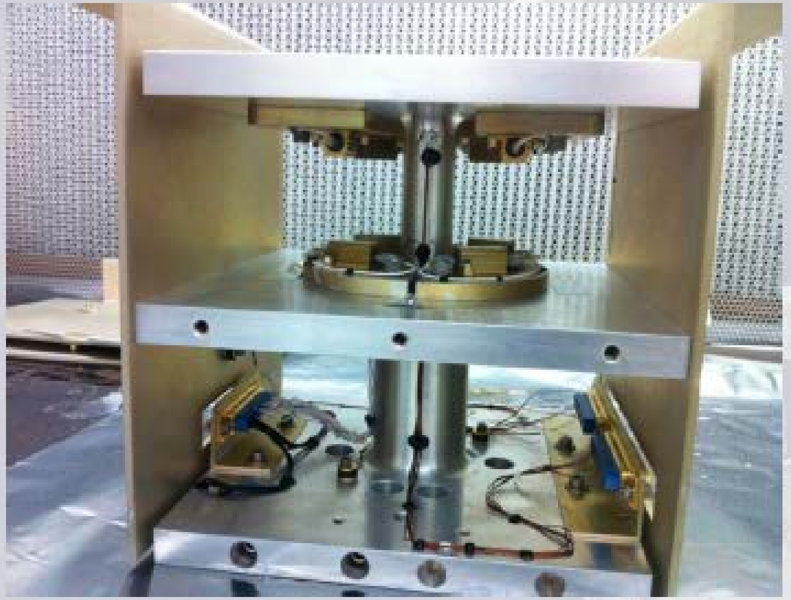
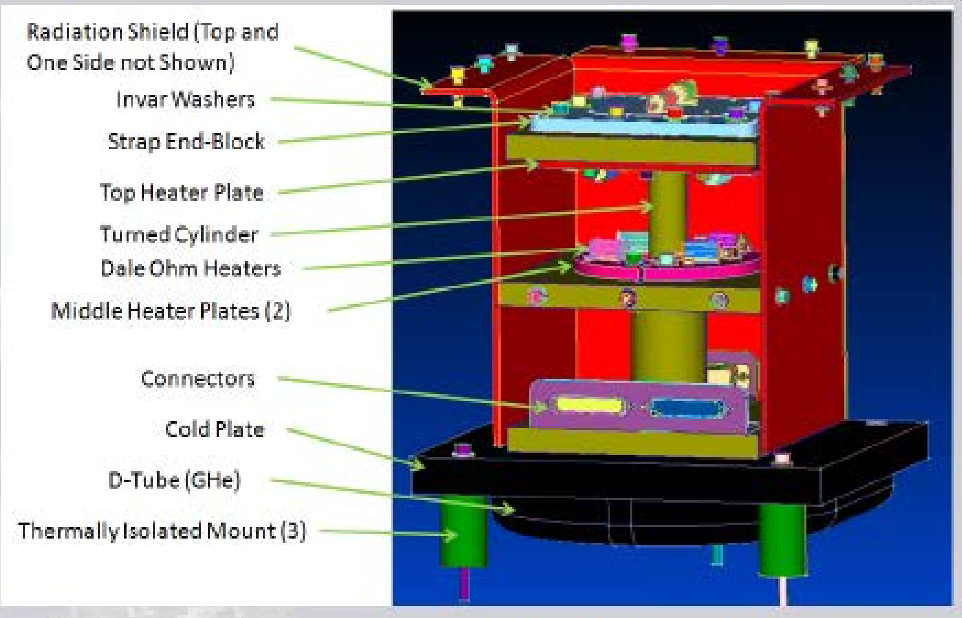
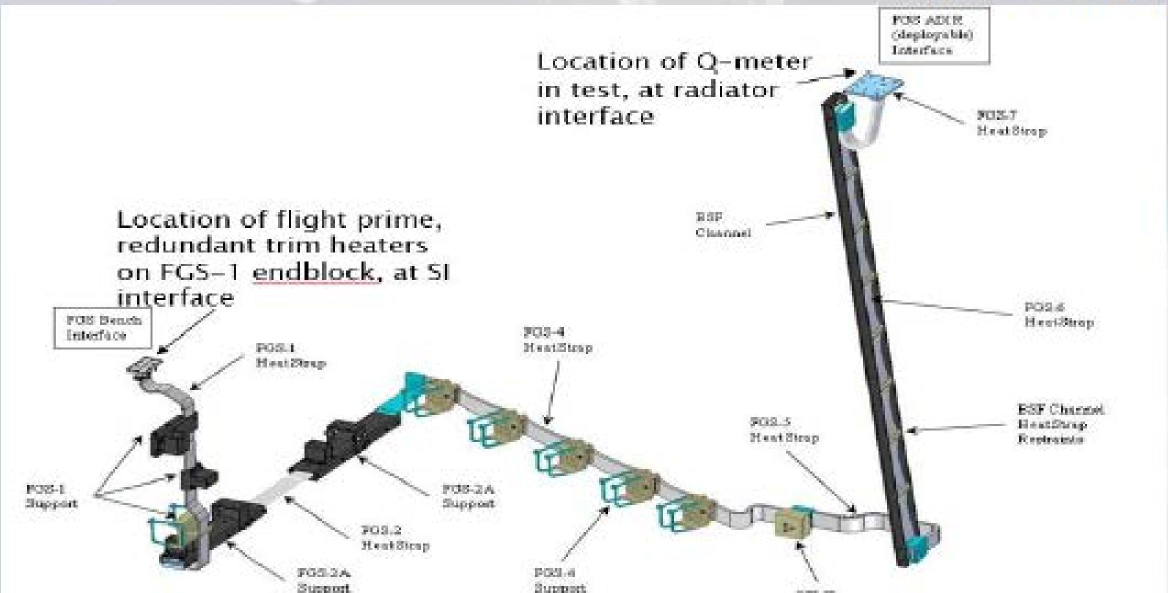


Photo of Q-meter during Initial Assembly

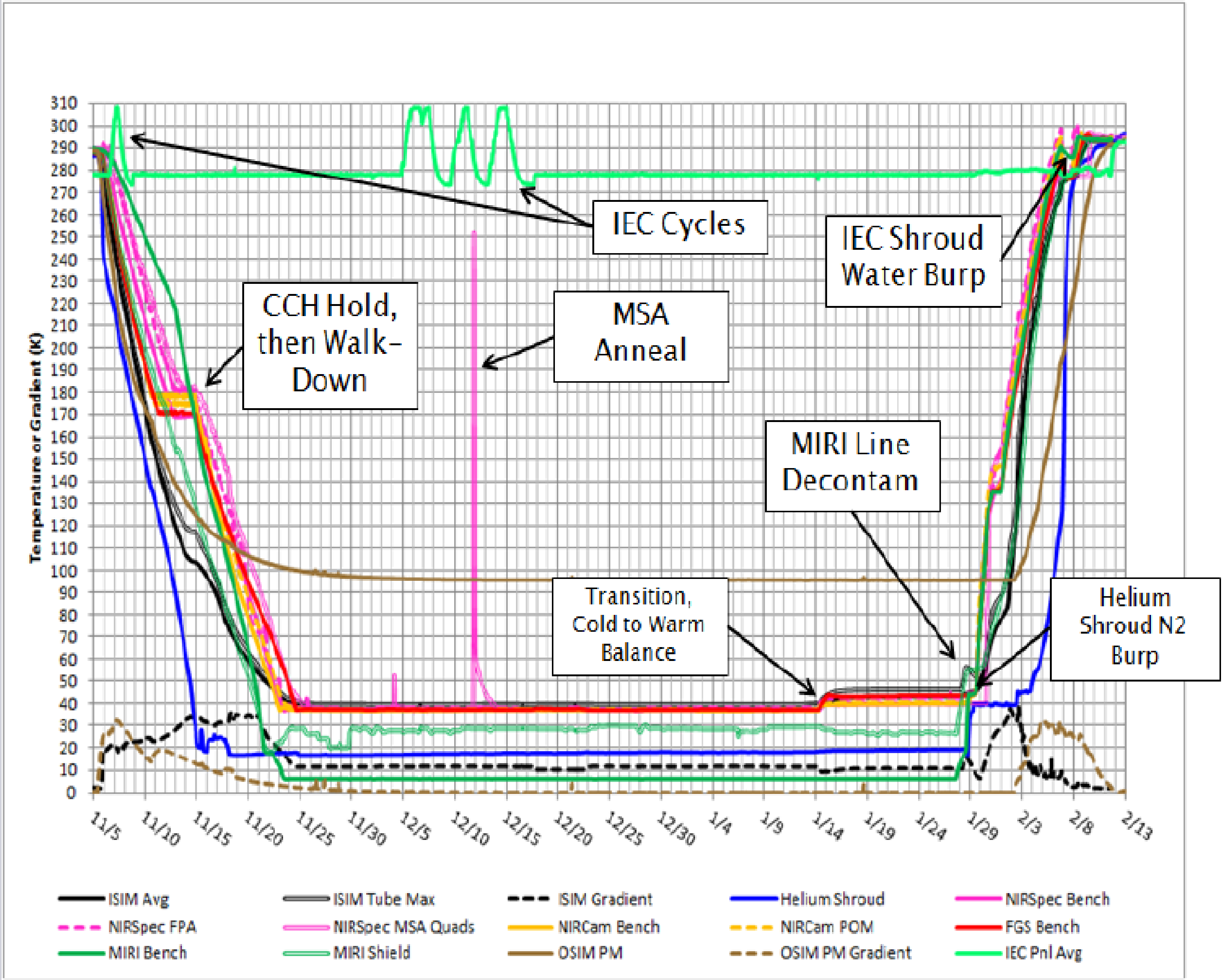


Q-meter Components

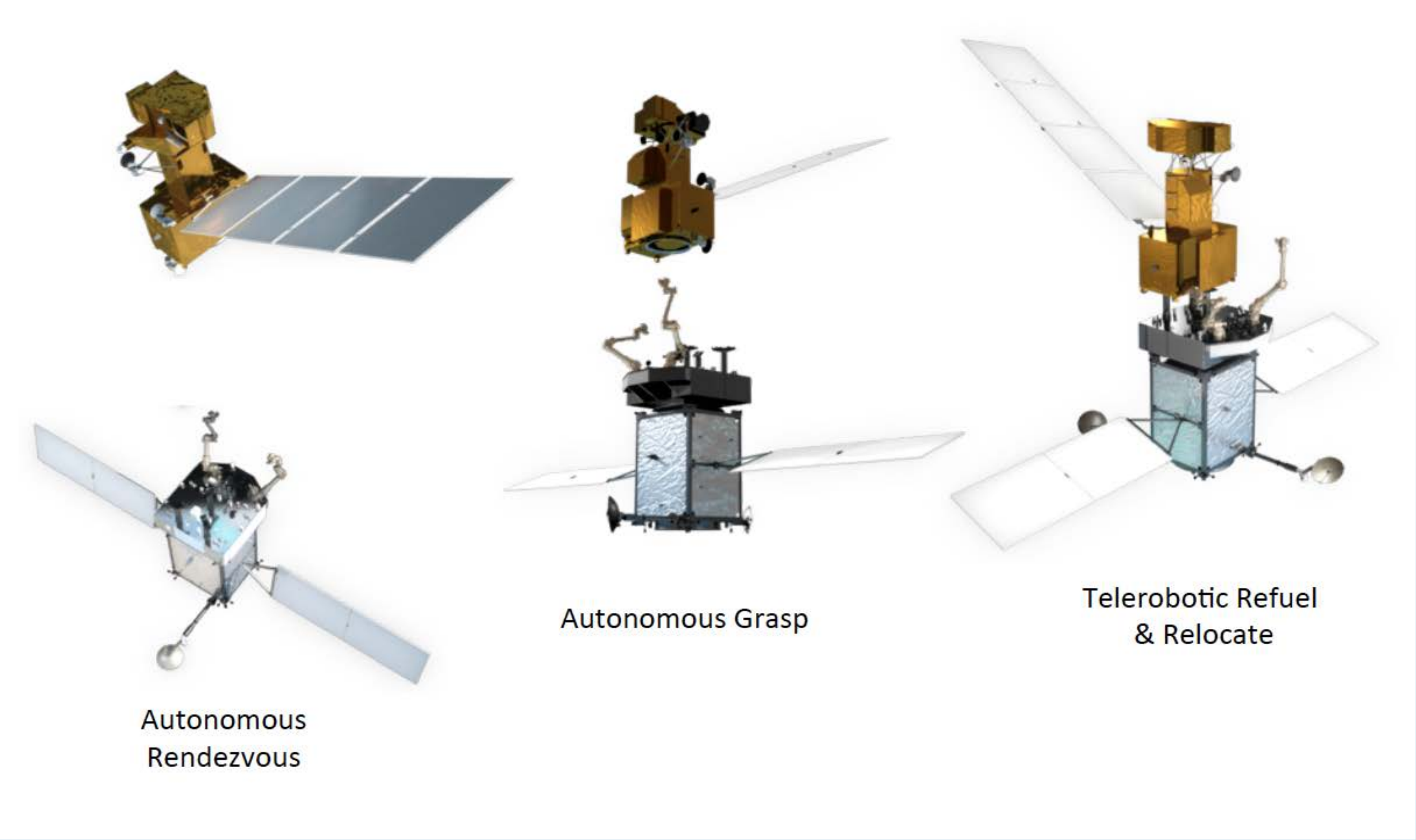
Typical mounting location of Q-meters in test (to heat strap at radiator interfaces), and location of trim heaters (on heat strap at instrument interfaces)



ISIM CV3 Test Profile



Satellite Servicing Projects

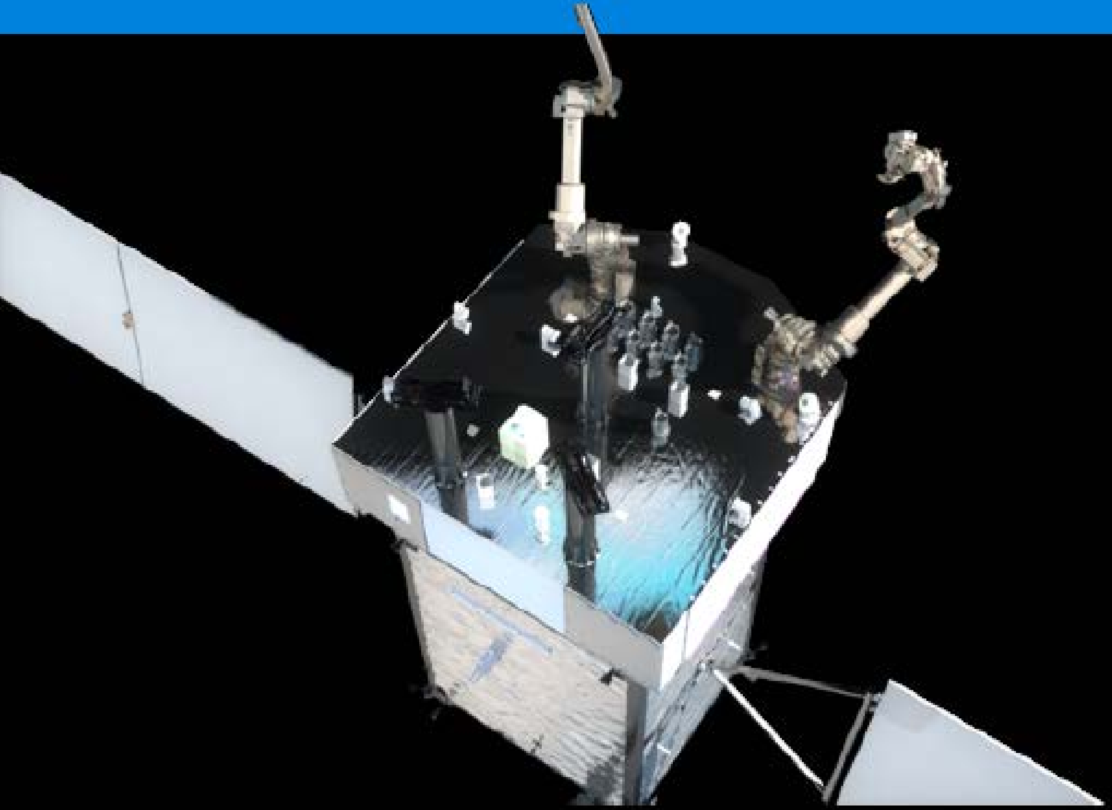


Restore L satellite will robotically refuel the Landsat 7 satellite
Numerous thermal issues + coatings must be electrically conductive

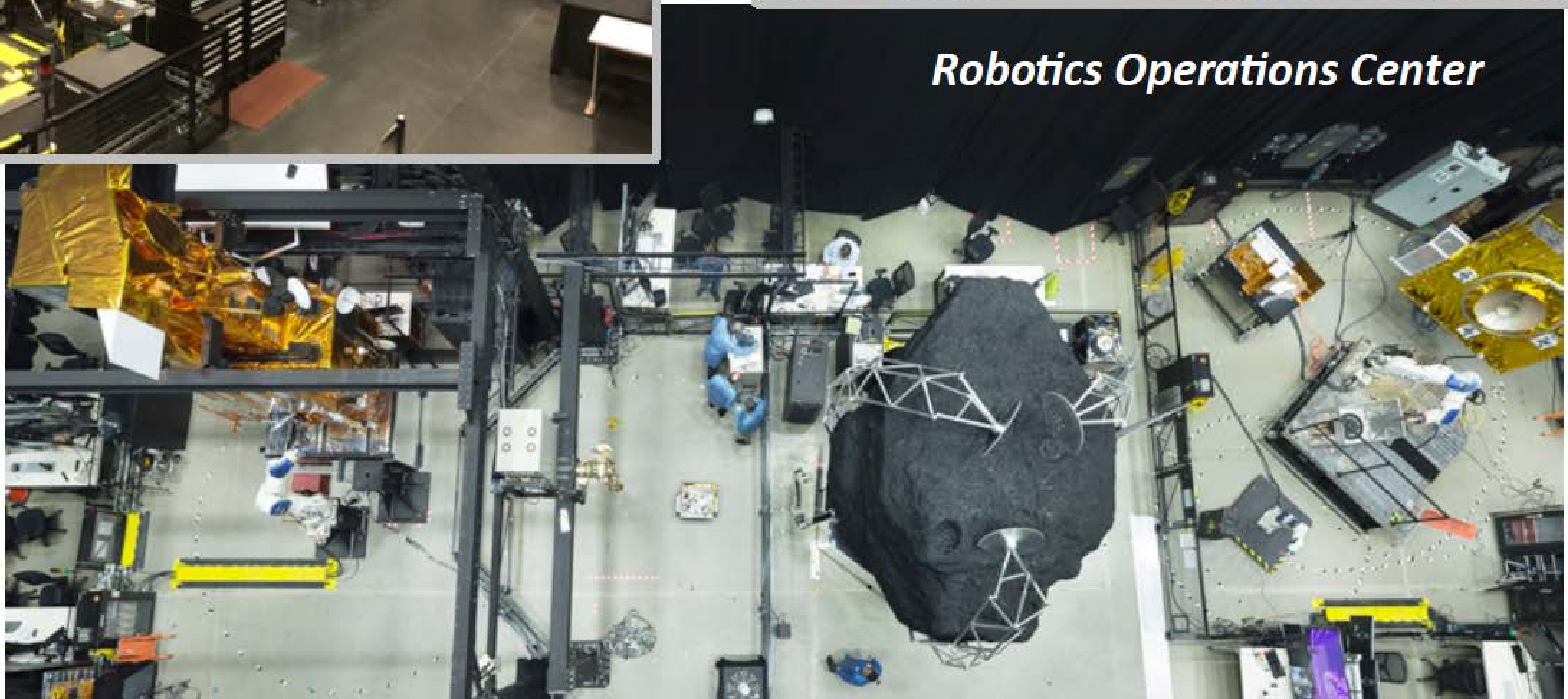
Technology Demonstration Mission

The Restore-L Mission will:

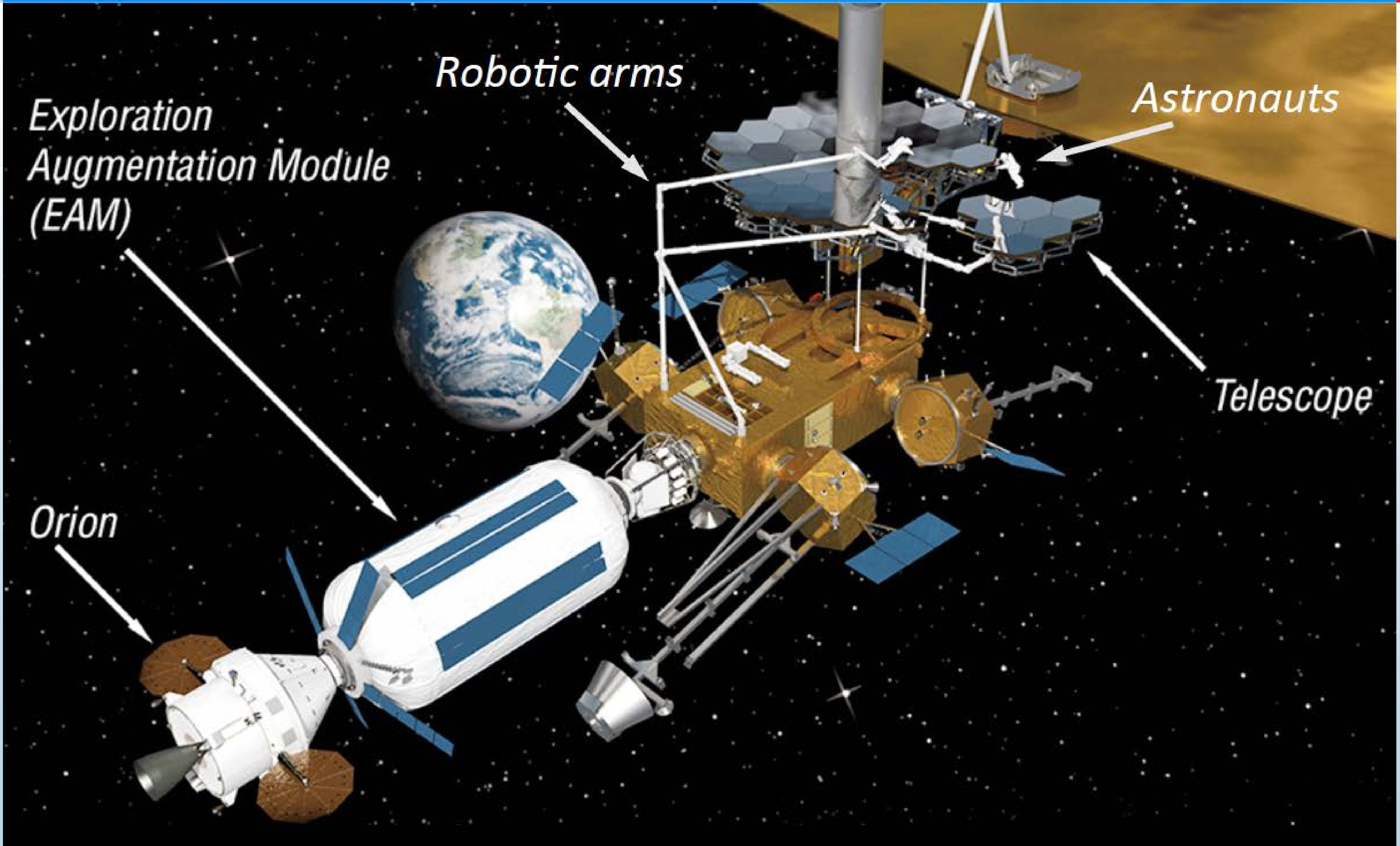
1. Demonstrate a national satellite servicing capabilities
2. Advance essential technologies for NASA and National goals
3. Kick-start a new U.S. commercial servicing industry



Robotics Facilities

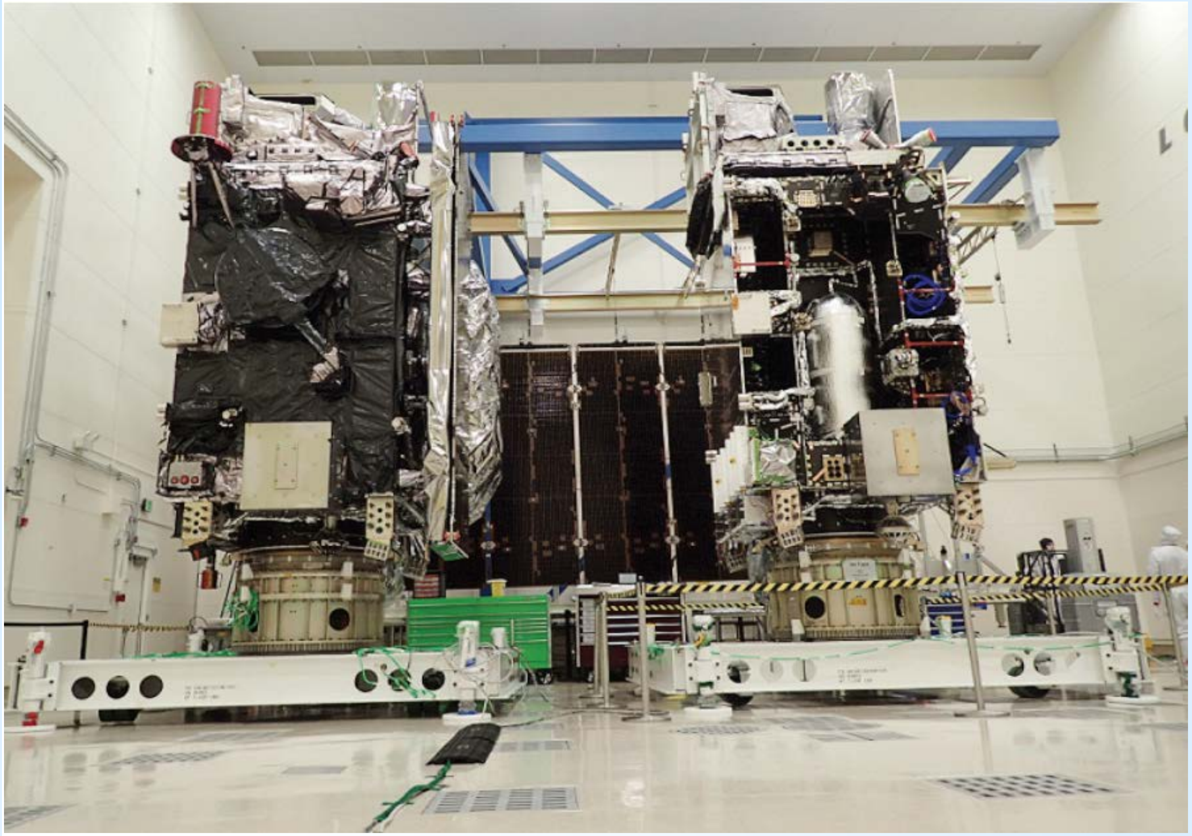


20 Meter?



Artist's Concept. NASA/SSPD

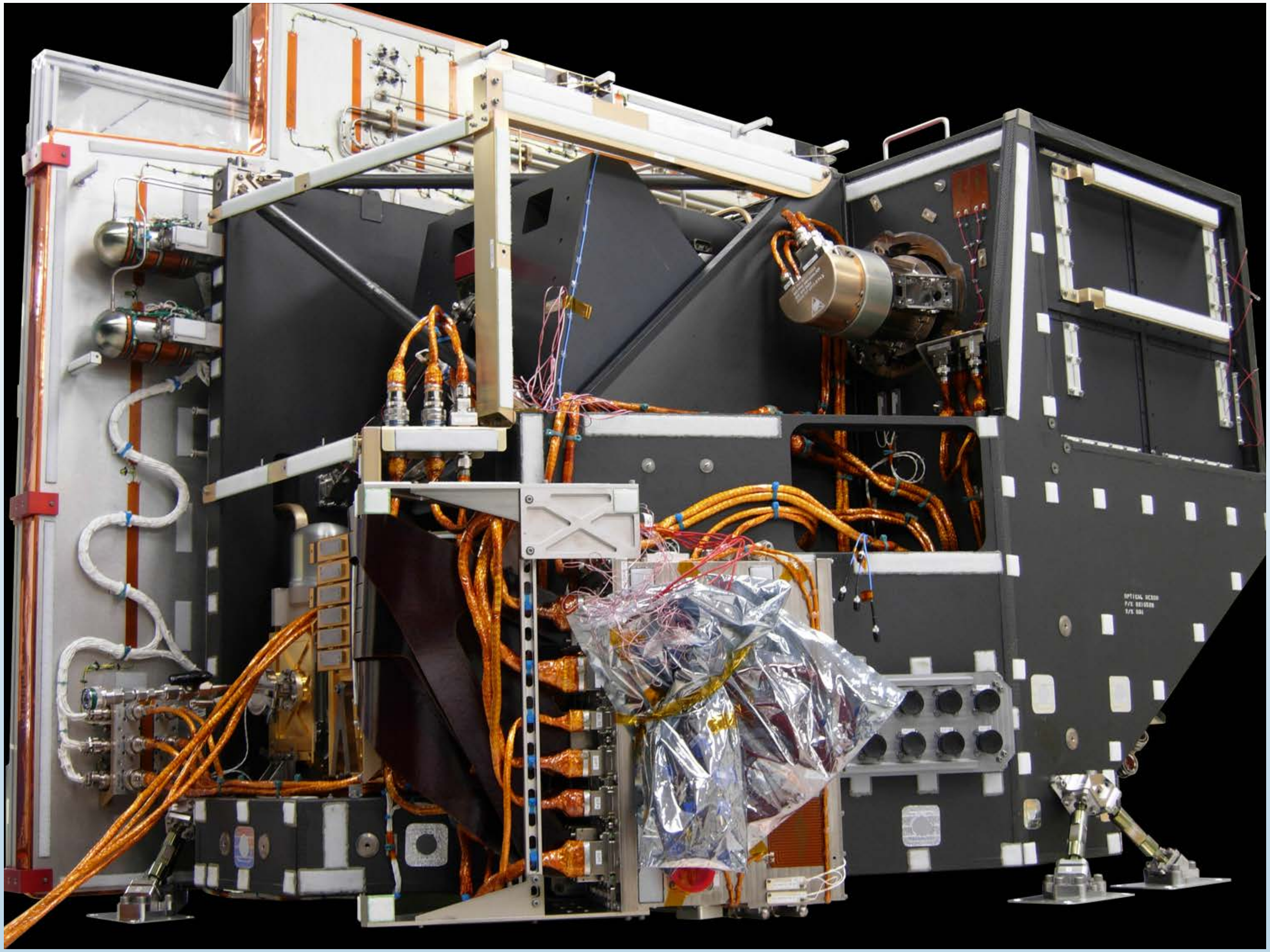
GOES-R and GOES-S in High Bay (Lockheed Martin, Denver CO)



GOES-R successfully launched and in orbit

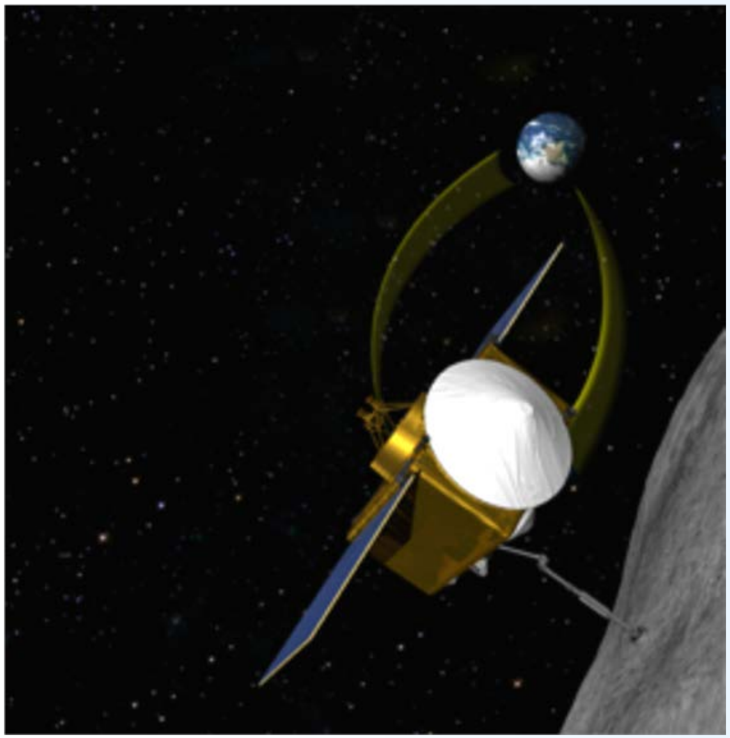
GOES-S TV test underway.

GOES-R ABI Instrument



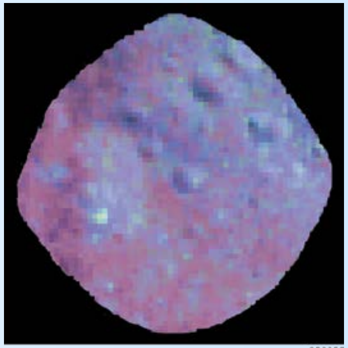
Working Issue with ABI Loop Heat Pipes. One LHP is taking most of the load and the other one can’t start - instrument can still run.

OSIRIS-REX – Asteroid Sample return

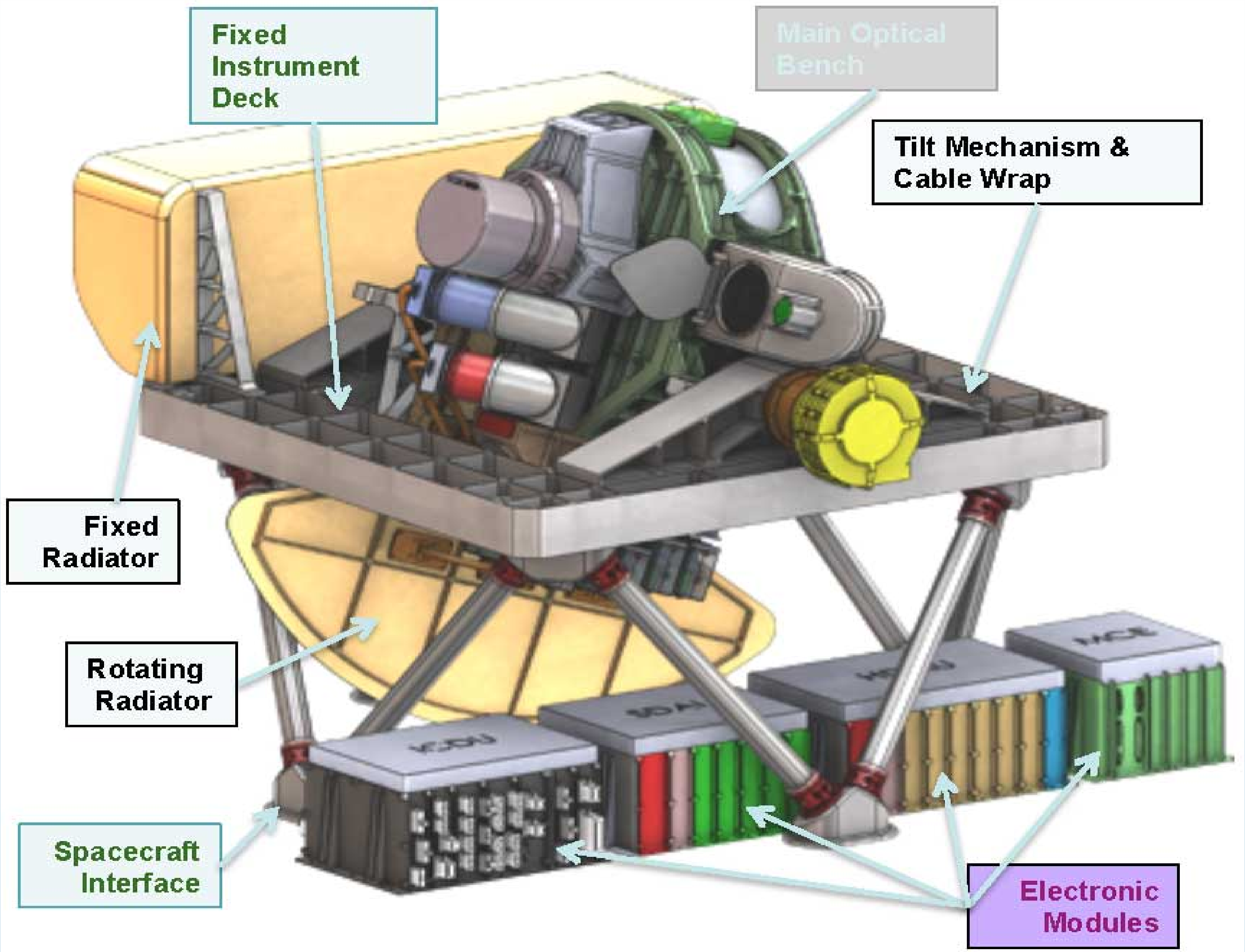


Launched Sept 2016
Asteroid Rendevous – 2018
Sample Return - 2023

Asteroid Bennu



PACE/Ocean Color Instrument (OCI)



PACE/OCI Mission

PACE - Plankton, Aerosol, Cloud, Ocean Ecosystem
OCI – Ocean Color Instrument
Polarimeter Instrument

PACE will be an in-house Spacecraft built at GSFC
OCI will also be in in-house build with Polarimeter from outside source

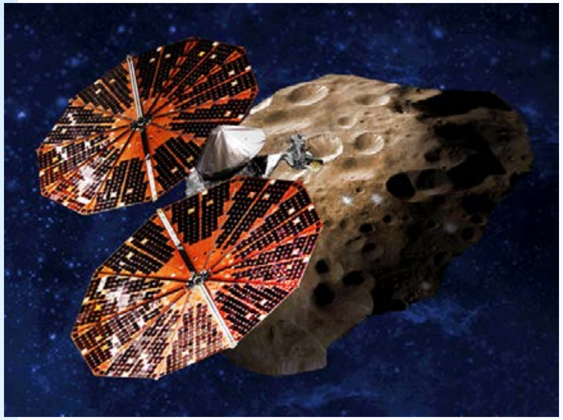
OCI detectors run in the -40 C to – 80 C range

Rotating radiator is a challenge (+/- 20 degrees) with 30,000+ cycles over mission
Cryogenic flexible heat pipes would be helpful, but not available yet, so flexible straps will be used

Additional Project Updates

ASTRO-H Recovery Mission approved – GSFC supplies instrument hardware (Cryocooler) and Japanese provide Spacecraft

Science very promising before mission failure due to mission ops issue – reached new low temp of 50 milli-Kelvin on orbit



New Mission - Lucy to study Jupiter's Trojan Asteroids – GSFC managed
Launch in 2021, Asteroid rendevous 2027

SWRI is PI, Lockheed-Martin Spacecraft

L-Ralph instrument in-house at GSFC – similar to New Horizons Pluto mission instrument

Emerging Thermal Control Technologies

- GSFC's SBIR Thermal Subtopic had a robust 2016 with participation from 3 NASA centers – GSFC, MSFC, and JPL
    - JPL will address their SBIR's in their talk
- IRAD funding received for 2 activities
- HQ funding for 1 activity

NASA SBIR/STTR Technologies

S3.07-8558 - Flexible Methane & Ethane Heat Pipes

PI: Calin Tarau

Advanced Cooling Technologies, Inc. - Lancaster, PA

Identification and Significance of Innovation

Constant Conductance Heat Pipes (CCHPs) are commonly used for spacecraft thermal control. Specific mission requirements can call for flexible heat pipes, to allow an instrument to track a target during orbit, to allow the deployment of radiator panels, or to minimize mechanical loads and vibration from a cryocooler into an instrument to be cooled. This SBIR program proposed by Advanced Cooling Technologies, Inc. (ACT) will design, fabricate, and demonstrate a cryogenic flexible CCHP for satellites. One main challenge of a flexible heat pipe is liquid collecting in the tight corners presented by the bellows geometry. ACT's concept to deal with this incorporates a wick structure in the tight corners of the bellows and moves liquid back to the main wick. The Phase II program will demonstrate flexible CCHPs with methane and ethane as the working fluid, for two relatively near term NASA applications. These CCHPs can also be used with ammonia, the standard heat pipe working fluid.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)

Technical Objectives and Work Plan

The Phase II technical objective is to develop mission-specific cryogenic flexible constant conductance heat pipes (CCHP), and verify their performance through detailed thermal and mechanical testing conducted in relevant environments and conditions. This will include optimizing the wick design for flexible heat pipes, and extending the capability of the wick design to integrate into additional bellows geometries. During the program, ACT will iteratively design, fabricate, and test prototype flexible heat pipes. The designs will be verified through testing. Final prototype hardware will be delivered to NASA for further feedback and evaluation The 9 technical tasks are: 1. Define Requirements, 2. Testing Requirements, 3. Task 3. Analysis and Modeling, 4. Thermal and Mechanical Design, 5. Bellows and Wick Development, 6. Preliminary Prototype Fabrication, 7. Preliminary Prototype Testing, 8. Full Scale Prototype Fabrication, and 9. Full Scale Prototype Testing.

NASA Applications

Two near-term NASA satellites require: 1. Flexibility to allow an instrument to move back and forth each orbit. 2. Flexibility to attach instruments to a cryocooler, damping vibrations. Methane and Ethane CCHPs will be developed in the Phase II program, but these heat pipes can also be used with ammonia, the most common working fluid. To date, flexible CCHPs have only been used in a few satellites, and have had problems with fluid accumulating in the flexible bellows. These problems will be removed with this new flexible CCHP.

Non-NASA Applications

CubeSats/SmallSats benefit from the flexible bend, allowing deployment of radiator panels. Flexible heat pipes can also be used in military and commercial terrestrial electronics. One example is using a flexible heat pipe to remove heat from an aircraft actuator. ACT has had a number of inquiries from customers on the availability of flexible heat pipes.

Firm Contacts

Calin Tarau
Advanced Cooling Technologies, Inc.
1046 New Holland Avenue
Lancaster, PA, 17601-5688
PHONE: (717) 295-6061
FAX: (717) 295-6064

NASA SBIR/STTR Technologies

S3.07-9425 - Innovations for the Affordable Conductive Thermal Control Material Systems for Space Applications

PI: Mukund Deshpande

Applied Material Systems Engineering, Inc. (AMSENG) - Schaumburg, IL

Identification and Significance of Innovation

NASA's increasingly needs sophisticated thermal control technologies for the instrumentation, sensors & the crafts. This innovative proposal is submitted to fulfill the identified needs: More sensitive instruments are resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for affordable conductive thermal control coatings, particularly with low absorptance, high emmittance, and good electrical conductivity. This Proposal plans to provide the innovative affordable products that are Space Stable, & Reliable. The technology Maturation & Validation is proposed in this phase II, based on the assessment in the phase I, so that the phase II E and Phase II X and the Phase III Technology Demonstration activity can be undertaken

Estimated TRL at beginning and end of contract: (Begin: 3 End: 6)

Technical Objectives and Work Plan

The objectives of the proposed efforts are to produce solid state chemistries for Li intercalated BNNT-BNNM™, Li:BNNM™, PBT-50™, KTO™, LTO™, (Li4Ti5O12) Whiskers and Doped (Si and Sn) [-Li(Al/Ga)O2] type highly conductive compounds to tailor the diffuse space environment stable TCMS that have the following performance characteristics:

- Total Solar Absorbance: BOL - μs < 0.10 (0.07 to 0.09 typical); EOL - μs @ 0.02 to 0.04 (LEO), μs @ 0.06 to 0.10 (GEO)
- Total Normal Thermal Emittance: BOL - eN @ 0.90 ± 0.05, EOL - eN @ 0.90 ± 0.05
- Surface Resistance: Rs = 1.0´103/ to 1.0´107/

These goals and various leakage current needs are planned to be met by processing reproducible Li Intercalated Boron Nitride Nano Tubes, Nano mesh (Li:BNNT-BNNM™, Li:BNNM™), LTO™, KTO™, LiTO™ Whiskers and Doped and Miscible (-LiAGO™: -Li(Al/Ga)O2) material systems to tailor the TCMS for the needed current carrying capabilities along with the unique optical and thermal space stable performance verification through GEO space simulation validation

NASA Applications

The Phase II can have greatest impact on the NASA missions that need white (low S/T) conductive TCMS coatings with needed current carrying capability. The candidate missions that can benefit from this technology uniquely are: Cube Sats Program, W-FIRST, DAVINCI, PACE, LANDSAT 9. It may also provide unique benefits to future missions like Europa and Mars 2020. Its affordable contributions to Cube Sat program can be timely and significant.

Non-NASA Applications

The DOD and Commercial missions need products that can benefit from this technology uniquely are:
DOD Cube Sats Program for High Radiation Environments, Survivable Second surface mirrors and TCMS that meet NRO hardening goals. Its affordable contributions to DOD and Commercial Cube Sat program can be timely and significant

Firm Contacts

Mukund Deshpande
Applied Material Systems Engineering, Inc. (AMSENG)
2309 Pennsbury Court
Schaumburg, IL, 60194-3884
PHONE: (630) 372-9650
FAX: (630) 372-9660

NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

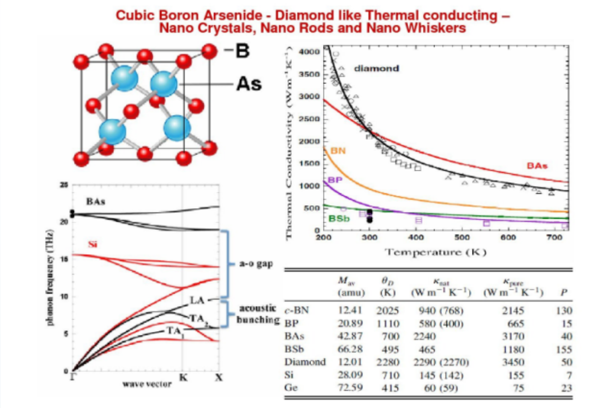
S3.07-8451 - Next Generation Thermal Management Materials: Boron Arsenide for Isotropic Diamond Like Thermal Conductivity - Affordable BAs Processing Innovations

PI: Mukund Deshpande
Applied Material Systems Engineering, Inc. (AMSENG) - Schaumburg, IL

Identification and Significance of Innovation

The Phase II goal are to design and carry out the materials and process engineering to demonstrate the scaled up processing of Phase Pure Cubic Boron Arsenide - Diamond like Thermal Conducting Nano Crystals, Nano Rods for designing advanced affordable thermal management material systems and products for the Space Systems Components for acquisition of heat from hot interfaces of high power RF devices, GaN transistors, and microprocessors etc. The ultimate aim is to reduce thermal resistance between hot components and cold plates; increase mechanical compliance; increase thermal cycles before degradation and ensure ease of workability and affordability using suggested Cubic Boron Arsenide product forms as conductive phases. The proposed concepts have potential for providing improved game changing products for the space systems components

Estimated TRL at beginning and end of contract: (Begin: 3 End: 6)



	M_{av} (amu)	θ_D (K)	κ_{nat} (W m^{-1} K^{-1})	κ_{pure} (W m^{-1} K^{-1})	P
c-BN	12.41	2025	940 (768)	2145	130
BP	20.89	1110	580 (400)	665	15
BAs	42.87	700	2240	3170	40
BSb	66.28	495	465	1180	155
Diamond	12.01	2280	2290 (2270)	3450	50
Si	28.09	710	145 (142)	155	7
Ge	72.59	415	60 (59)	75	23

Technical Objectives and Work Plan

- Process Novel Cubic Boron Arsenide - Diamond like Thermal conducting - Nano Crystals, and Nano Rods using Phase I successful process paths
- Scale up & Reliability Validation for affordable Novel Cubic Boron Arsenide - Nano Crystals, and Nano Rods based Products for Space Thermal Management Applications
- Characterization of produced Novel Cubic Boron Arsenide - Nano Crystals, and Nano Rods via XRD, FTIR, SEM, TEM and HRTEM
- Concept Product modeling and Conceptual Material & Processing Design Developments - Study affordability Needs
- Use of the Novel Cubic Boron Arsenide - Nano Crystals, and Nano Rods to formulate and tailor needed Space Thermal Management Material Systems (TMMS) and Products for the enhanced performance
- Flash diffusivity & Steady State Thermal Conductivity characterization of the Novel Cubic Boron Arsenide Nano Crystals, and Nano Rods based products for the TMMS and TIMS

NASA Applications

- Cubic Boron Arsenide - Diamond like Thermal conducting Nano Crystals, and Nano Rods based High Heat Flux - Thermal Management Material Systems and Products for Space Applications with enhanced performance and reliability - All NASA Earth Science and Exploration missions
- The High-K Concept Nano Composites Using Cubic Nano Boron Arsenide from AMSENG for Thermal Management Products with enhanced durability for NASA Small Sats and Cube Sats

Non-NASA Applications

- Cubic Boron Arsenide - Diamond like Thermal conducting Nano Crystals and Nano Rods based Thermal Management Material Systems and Products meeting the performance goals identified by DoD Missions and NRO
- Survivable Cubic Boron Arsenide - Diamond like Thermal conducting Nano Crystals, and Nano Rods based Nano Composites for the Commercial &

Firm Contacts

Mukund Deshpande
Applied Material Systems Engineering, Inc. (AMSENG)
2309 Pennsbury Court
Schaumburg, IL, 60194-3884
PHONE: (630) 372-9650
FAX: (630) 372-9660

NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

S3.07-8563 - Loop Heat Pipe Manufacturing via DMLS for CubeSAT Applications

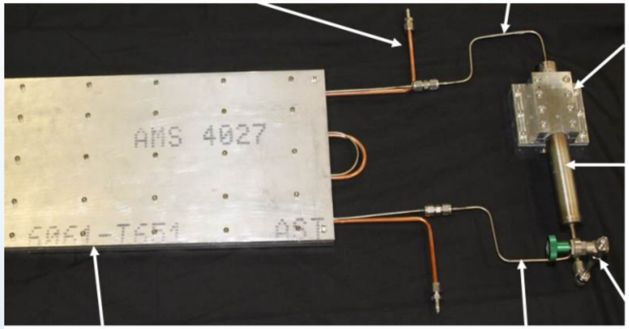
PI: William Anderson

Advanced Cooling Technologies, Inc. - Lancaster, PA

Identification and Significance of Innovation

It is estimated that the cost to produce a Loop Heat Pipe (LHP) pump assembly, accounts for approximately 75% of the total system's manufacturing cost. By 3D printing an evaporator envelope with an integral porous primary wick structure, the overall complexity and cost of the design can be significantly reduced. One advantage is that the Direct Metal Laser Sintering (DMLS) method offers is that many aspects of the fabrication process can be simplified and dissimilar metal joints can eliminated. In addition to the direct benefits, this novel fabrication method enables additional enhancements due to the inherent advantages of the additive manufacturing method which eliminates some restrictions of traditional machining, enabling structures that are more favorable from a thermal and hydrodynamic perspective. In Phase I, a LHP with a DMLS evaporator was built using ammonia as the fluid, and carried the predicted 45 W.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)



Technical Objectives and Work Plan

The overall objective of the Phase I and Phase II programs is to develop a low cost LHP, where the pump is fabricated by DMLS technology. Due to time and cost limitations, the Phase I program developed a sub-scale pump, with a single pore size wick, envelope, bayonet, knife edge, and axial grooves. The overall objective of the Phase II program is to develop the additional processes required, then to fabricate and demonstrate a full scale LHP, with the pump fabricated by 3-D printing. A second LHP will be fabricated that is suitable for testing on the ISS. The 9 technical tasks are: 1. Define Requirements, 2. Pore Radius and Permeability Study, to optimize the DMLS parameters, 3. Scaling Study, to scale the LHP evaporator, 4. Accelerated Life Testing, verifying the compatibility of the DMLS evaporator, and the overall LHP, 5. LHP Miniaturization, to fit onto a SmallSat, 6. Graded Wick Fabrication, to improve performance, 7. Secondary Wick Fabrication, to lower fabrication costs, 8. Prototype Design of a complete LHP, 9. LHP Fabrication and Testing, including thermal vacuum, and shock/vibration testing, and 10. Flight LHP Fabrication and Testing, using a working fluid that would allow the LHP to be tested on the ISS.

NASA Applications

Ammonia and propylene LHPs are currently used in most NASA and commercial satellites. In comparison with Constant Conductance Heat Pipes, they carry much higher powers (1 kW vs. 100 W) over longer distances (10 m vs. 2-3 m). Their main drawback is that they are two orders of magnitude more expensive to fabricate and test than CCHPs. A major benefit of the proposed evaporator/wick fabrication will be a significant reduction in cost of LHPs supplied to NASA for SmallSat/CubeSat applications.

Non-NASA Applications

The benefits for the Air Force are similar to the benefits for NASA. The commercial communications satellite market is the current primary market for LHPs. Universities are able to fabricate their own CubeSats for research in space; however, their budgets are much too limited to allow them to use LHPs. They could benefit from 3D printed LHPs, since the cost can be significantly reduced.

Firm Contacts

William Anderson
Advanced Cooling Technologies, Inc.
1046 New Holland Avenue
Lancaster, PA, 17601-5688
PHONE: (717) 295-6061
FAX: (717) 295-6064

NASA SBIR/STTR Technologies

S3.07-8574 - Advanced Multiphysics Ablation Simulation Framework

PI: Eric Blades

ATA Engineering, Inc. - San Diego, CA

Identification and Significance of Innovation

The proposed effort seeks to mature and validate an innovative approach to multiphysics simulation of ablative structures in extreme operating environments. ATA's approach tightly integrates the CHarring Ablator Response (CHAR) three-dimensional implicit charring ablator solver, the Loci/CHEM (CHEM) computational fluid dynamics solver for high-speed chemically reacting flows, and the Abaqus nonlinear structural dynamics solver to create a fully coupled aerothermoelastic charring ablative solver. These well-validated constituent codes are coupled in a simulation framework via an interface largely invisible to the user and which offers many advantages over the current state of the art. The planned capabilities are not currently available and will be valuable for modeling problems utilizing ablative materials. The increase in prediction accuracy offered by the fully coupled methodology will enable higher-fidelity thermal protection systems that can be optimized for safety and low weight. Reduction in TPS mass translates directly to gains in performance margin or payload weight.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)

Technical Objectives and Work Plan

Technical Objectives
1. Increase usability of the multiphysics framework
2. Increase functionality of the multiphysics framework
3. Extend physics in CHEM to address nonequilibrium hypersonic flows
4. Conduct further validation of multiphysics framework

Work Plan
Task 1: Develop tools to aid multiphysics problem setup
Task 2: Implement usability and functionality enhancement (axisymmetric capability, update for compatibility with current versions of the multiphysics solvers, develop postprocessing capability for abaqus UEL usability)
Task 3: Implement and verify thermal nonequilibrium model (implement thermal nonequilibrium model using scalar transport equations, implement numerical techniques to increase stability of thermal nonequilibrium models, verify implementation of thermal nonequilibrium models)
Task 4: Perform validation simulations (develop multiphysics models, define metrics and criteria for analysis framework validation, aerothermoelastic validation case, ablative aerothermoelastic validation case, ablative aerothermoelastic entry validation case)

NASA Applications

SLS (propulsion nozzle ablation and base heating, crew capsule TPS)
Evolvable Mars Campaign

Non-NASA Applications

Ballistic re-entry vehicles
Hypersonic vehicles
Commercial spacecraft (space tourism)
Defense missile systems
Solid rocket motors
Directed energy weapons effect (laser ablation)

Firm Contacts

Joshua Davis
ATA Engineering, Inc.
13290 Evening Creek Drive South, Suite 250
San Diego, CA, 92128-4695
PHONE: (858) 480-2000
FAX: (858) 792-8932

NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

S3.07-7701 - Lightweight Flexible Thermal Energy Management Panels for CubeSats

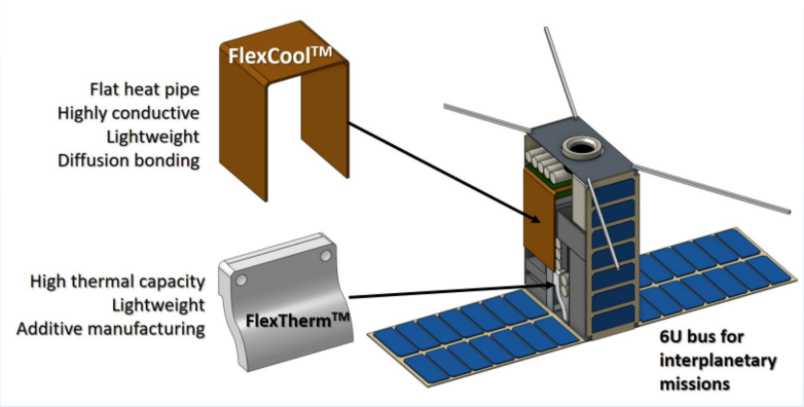
PI: Diego Arias

ROCCOR, LLC - Longmont, CO

Identification and Significance of Innovation

Under this program, Roccor is developing two critically needed thermal management devices for CubeSats: a so-called FlexTherm™ thin light-weight PCM thermal energy storage panel and a so-called FlexCool™ thin conformable micro heat pipe for thermal energy transport. Figure 6 (left) shows an exploded view of a FlexTherm™ panel, which includes a layer of PCM encased in a 3D printed metal enclosure. Figure 6 (right) illustrates how such a panel might be coupled with one of Roccor's FlexCool™ two-phase micro heat pipe thermal strap to accept waste heat from a CubeSat printed circuit board (PCB). The innovation common to both FlexTherm™ and FlexCool™ devices is the application of advanced manufacturing technologies that yield simpler mechanical designs and provide excellent specific thermal performance (i.e., thermal energy/device mass and volume) enabling high-power CubeSat applications.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)



Technical Objectives and Work Plan

- Identify the thermal management challenges of the MSU's 6U common bus, and translate them into specific requirements and performance metrics.
- Develop and validate a high fidelity thermo-structural model of the FlexTherm PCM panels, incorporating the effect of complex internal structure and PCM materials.
- Update and validate design and performance models for flat heat pipes, in order to use methanol as working fluid in copper heat pipes.
- Design FlexTherm and FlexCool devices that meet performance and structural targets.
- Demonstrate robust manufacturing FlexTherm PMC panels.
- Manufacture structurally robust and thermally efficient FlexCool heat.
- Formulate a manufacturing plan that extends beyond the Phase II project.
- Develop a map of thermal performance response of the FlexTherm and FlexCool devices
- Integrate devices into the Lunar IceCube 6U interplanetary CubeSat bus
- Demonstrate the performance through environmental testing of the integrated Lunar IceCube spacecraft.
- Disseminate data collected in open, scientific literature

NASA Applications

The primary NASA target application for the proposed FlexTherm™ PCM panel technology and FlexCool™ micro heat pipe technology is future NASA CubeSat and SmallSat spacecraft for which thermal control of on-board electronics is a major bottleneck in the system design. NASA has a growing commitment to developing CubeSat technologies and flying meaningful CubeSat science missions, and Roccor is vigorously working to be a value-added thermal management system provider to the next generation of NASA science CubeSats to be flown as early as 2020.

Non-NASA Applications

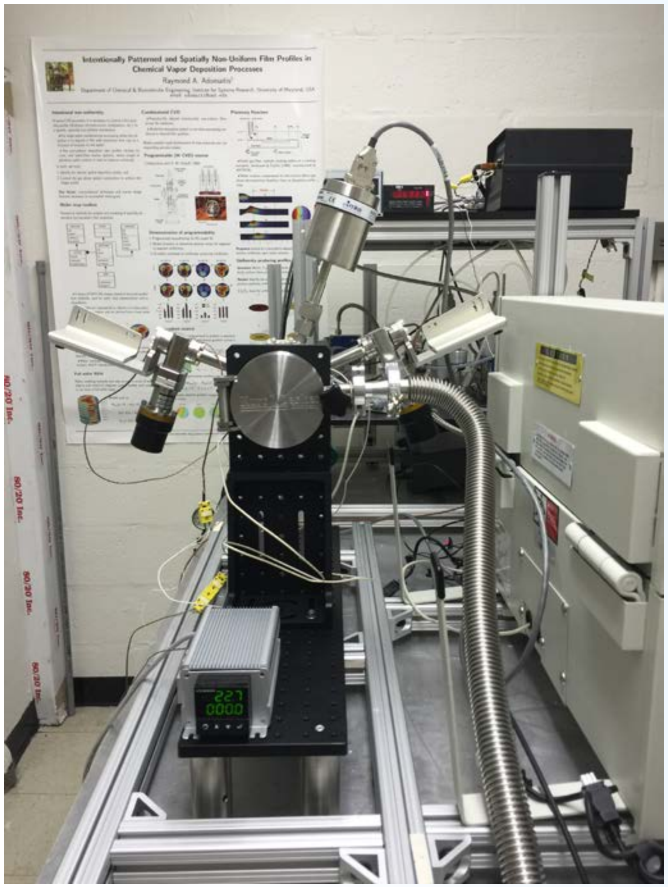
Estimates of the small satellite market forecast a significant growth in the segment of nano-micro satellites during the next few years; further demonstrated by the announcements of SpaceX and OneWeb to develop constellations of 4,025 and 648 satellites, respectively. Roccor is positioning our FlexTherm™ and FlexCool™ products to serve this growing market of small CubeSats beyond NASA missions.

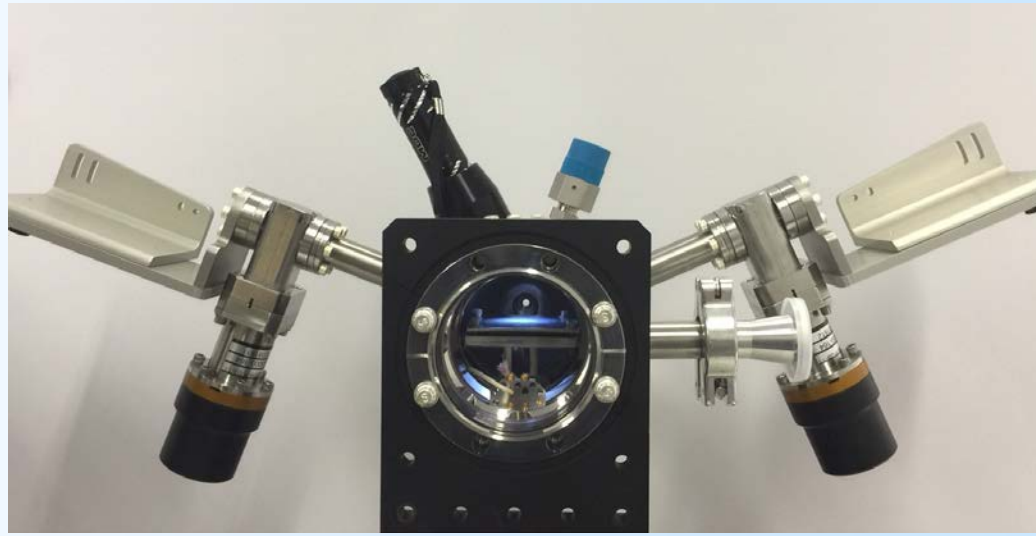
Firm Contacts

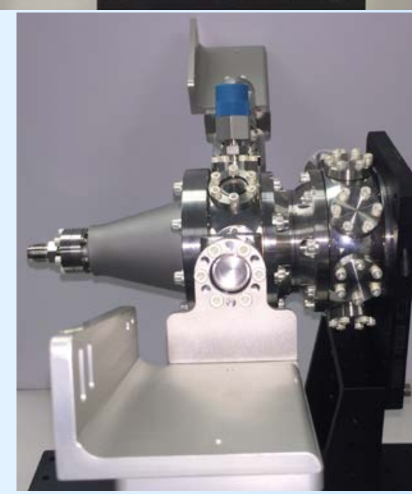
Diego Arias
ROCCOR, LLC
2602 Clover Basin Drive, Suite D
Longmont, CO, 80503-7555
PHONE: (720) 200-0068

Atomic Layer Deposition - Update

IRAD Dr. Vivek H. Dwivedi - PI

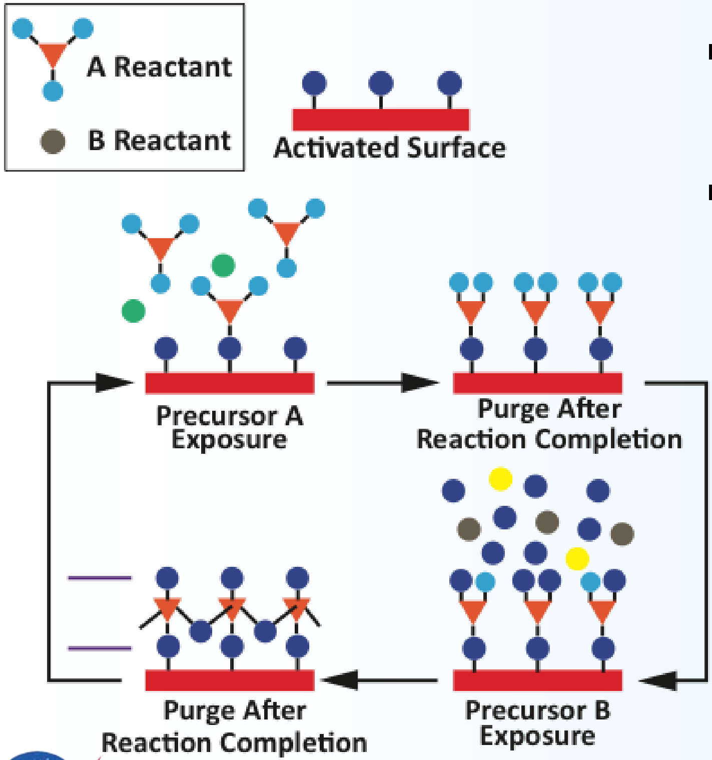






ALD – Atomic Layer Deposition

A thin film"nanomanufacturing" tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.



- Paired gas surface reaction chemistries
- Benign non-destructive temperature and pressure environment
  - Room temperature -> 250 ° C (even lower around 45 ° C)
  - Vacuum

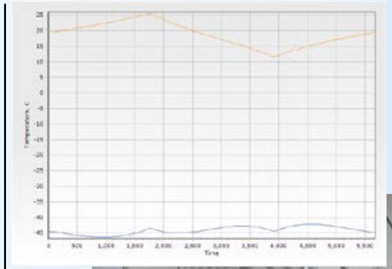
Passive Thermal Films

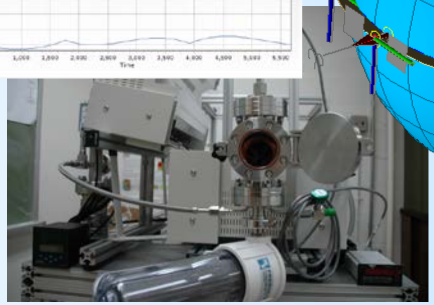
Description and Objectives:

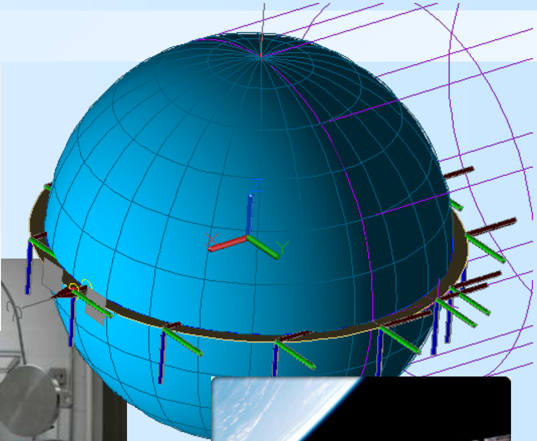
Trending towards reduced power and mass budget on satellites with a longer mission life, there is a need for a reliable thermal control system that is more efficient and cost-effective. Vanadium dioxide, VO_2, is a transition metal oxide that undergoes a passive thermal phase change from a semiconductor to a metal at 67 C. By depositing nm thick VO_2 via an in house atomic layer deposition (ALD) reactor, passive thermal control for solar cells, radiators and external boxes with minimized weight.

Key challenge(s)/Innovation:

By utilizing a novel liquid based vanadium source deposition is possible in benign environments. By adding ALD based dopants temp transition will trend low.







Approach:

Demonstrate the applicability of a custom built in-house ALD system to coat crystalline vanadium oxide films as well as films of doped vanadium oxide via an ALD doping technique to achieve a transition temperature at or below 67 C. Test the transition temperature using a cost effective set-up.

Application / Mission:

- CubeSat (LWaDI)
- Radiators
- Shape Shifting Radiator

Collaborators:

Raymond Adomaitis (UMD), NRL, Code 695

Milestones and Schedule:

- Reactor Check-out Dec 2015
- VO2 Growth March 2016
- Full Characterization

Space Technology Roadmap Mapping:

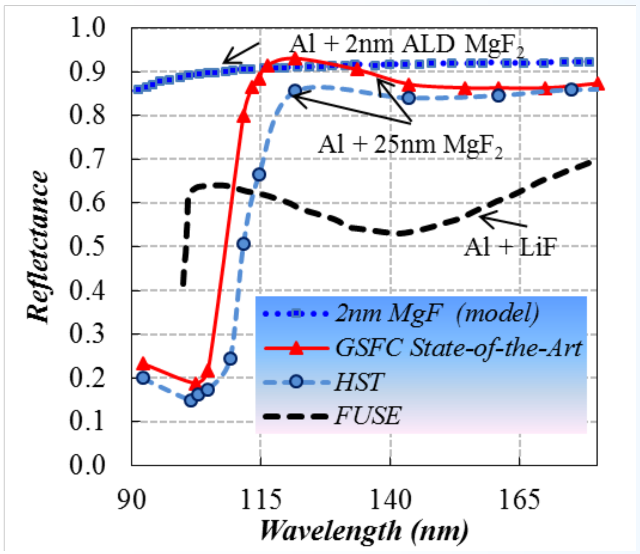
- Primary Technical Area: TA14
- Secondary Technical Area: TA10
- Additional Technical Area(s): TA12
- Applicable Space Technology Grand Challenge: Surviving Space Environments

Technology Readiness Level:

- Starting TRL: 3
- Anticipated Ending TRL:6

Far Ultra-Violet(FUV)Reflectance Coating

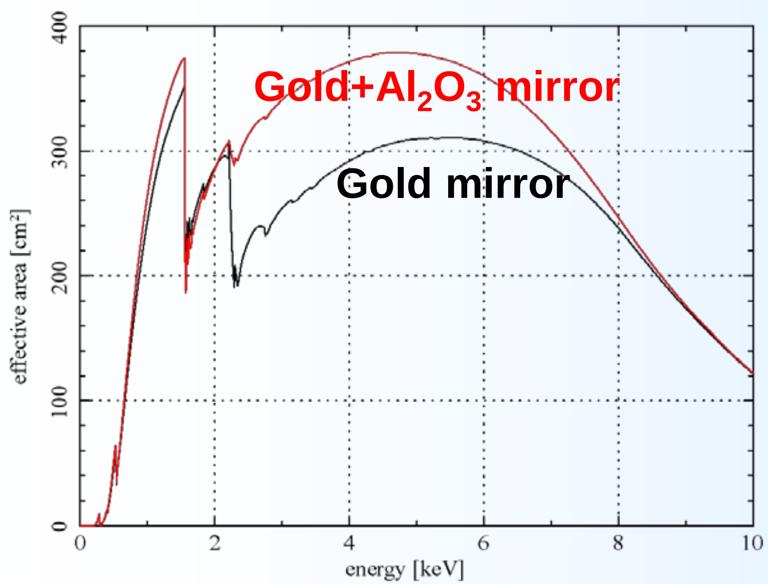
Ultraviolet range of 90-130 nm is one of the biggest constraints on FUV telescope and spectrograph design, and it limits the science return of FUV-sensitive space missions. Improved reflective coatings for optics could yield dramatically more sensitive instruments and permit more instrument design freedom.

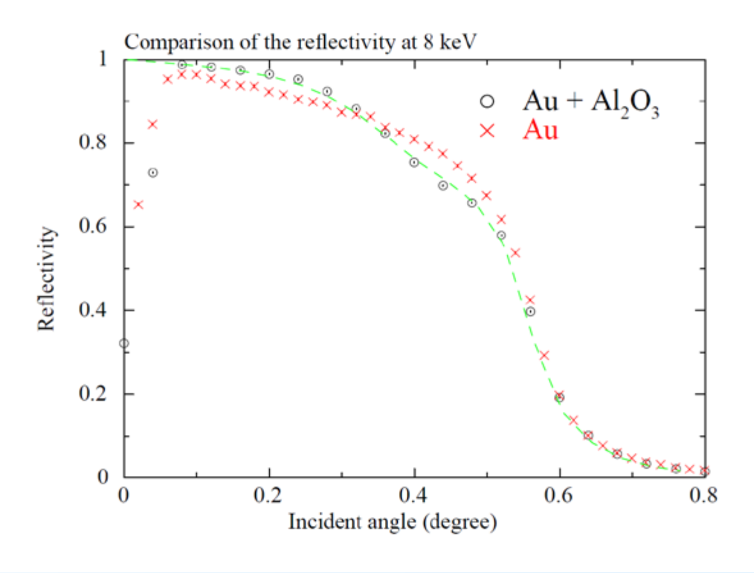


- ❖ Large UV / Optical / Infrared Surveyor
- ❖ A space telescope concept in tradition of Hubble
  - Broad science capabilities
  - Far-UV to Near-IR bandpass
  - ~16 m aperture diameter
  - Suite of imagers and spectrographs
  - Serviceable and upgradable

- ALD Film Deposition of AlF3 utilizing Halogenated Precursor and organometallic)
- ALD Film Deposition of AlF3 on etched coupons of XeF2

Room Temperature ALD for X-ray Applications





***5 nm thick ALD Al2O3 layer is applied on the gold surface**
***Reflectivity can be increased substantially in soft X-ray band**

Flow Boiling in Microgap Coolers – an Enabling Technology for 3D Integrated Circuits

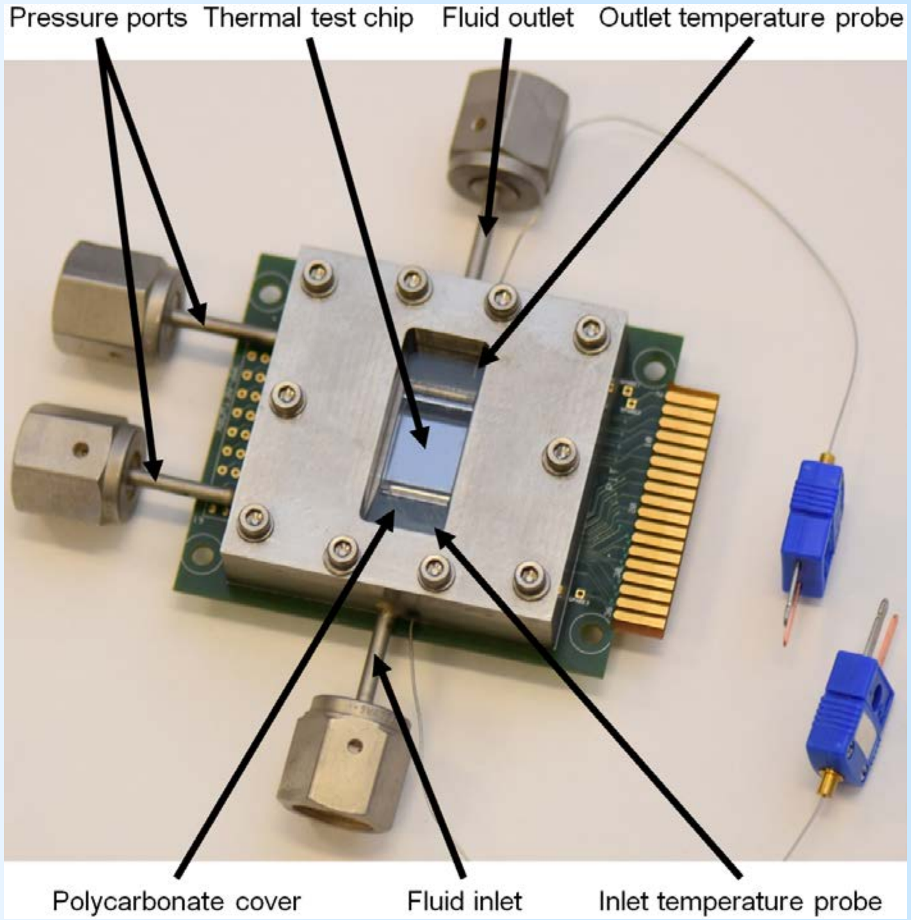
Frank Robinson
Principal Investigator
franklin.l.robinson@nasa.gov

FY17 Goals

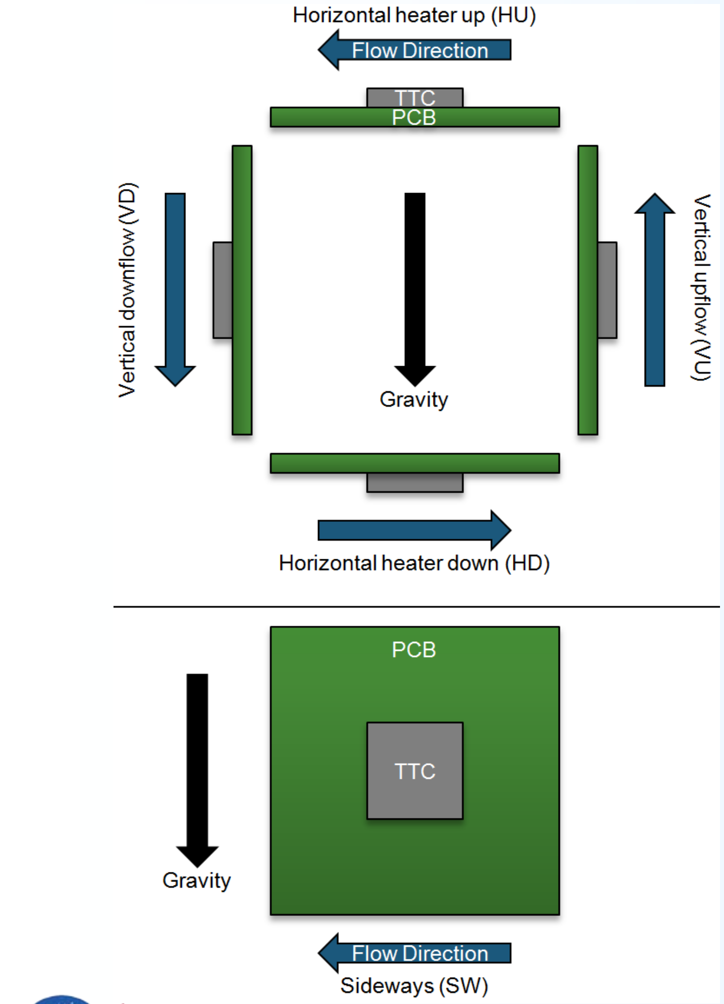
1. Characterize the role of channel size and fluid velocity on flow boiling orientation-independence
2. Assess the thermal capabilities of embedded microgap coolers in 3D chip stacks
3. Quantify system-level space, weight, and power advantages of embedded microgap coolers in a demonstration unit

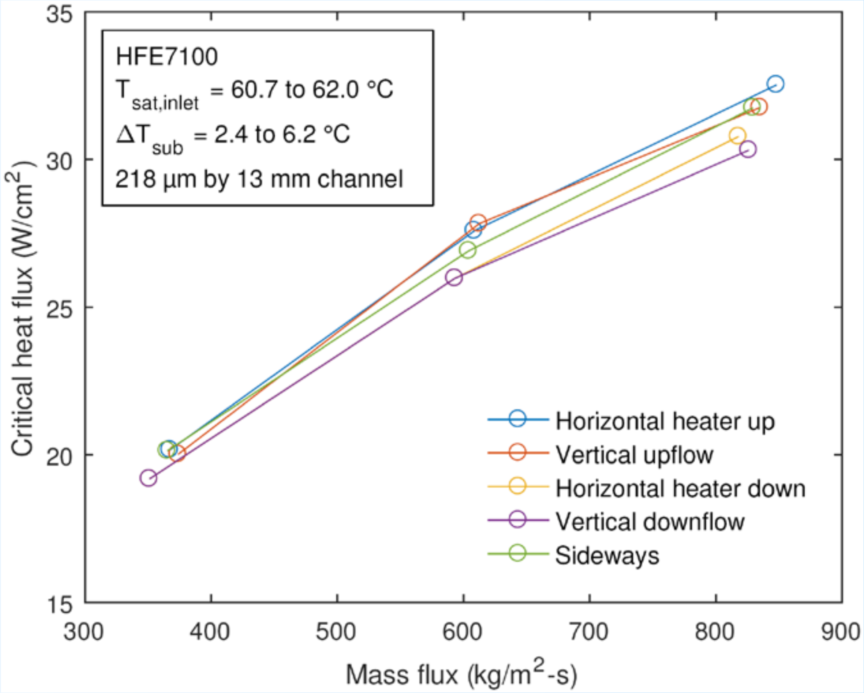
Evaporator Assembly

- Thermal test chip
  - 12.7 x 12.7 mm^2
  - Uniform heat flux
  - 10 temperature sensors
- Single, low-aspect ratio channel (i.e., microgap)
  - Inserts to change channel height



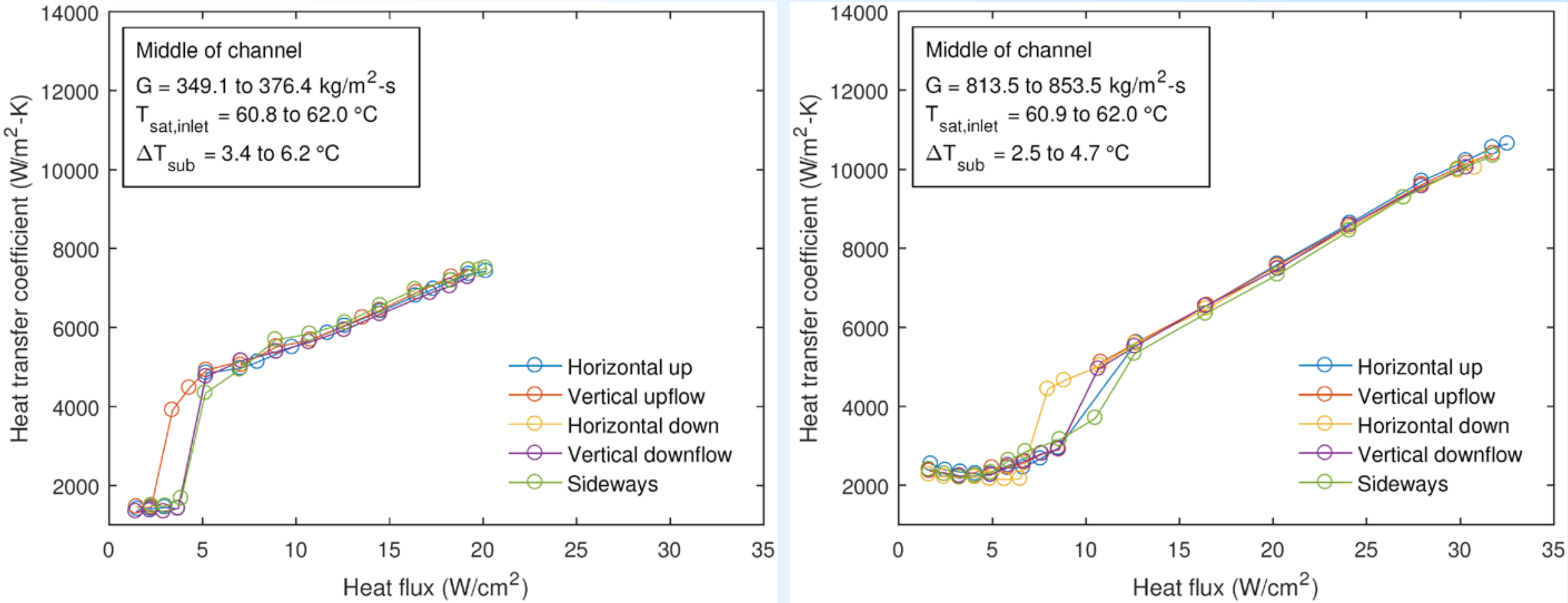
Orientation Independent Critical Heat Flux (CHF)





Minor variation in CHF across orientations likely attributable to variation in mass flux

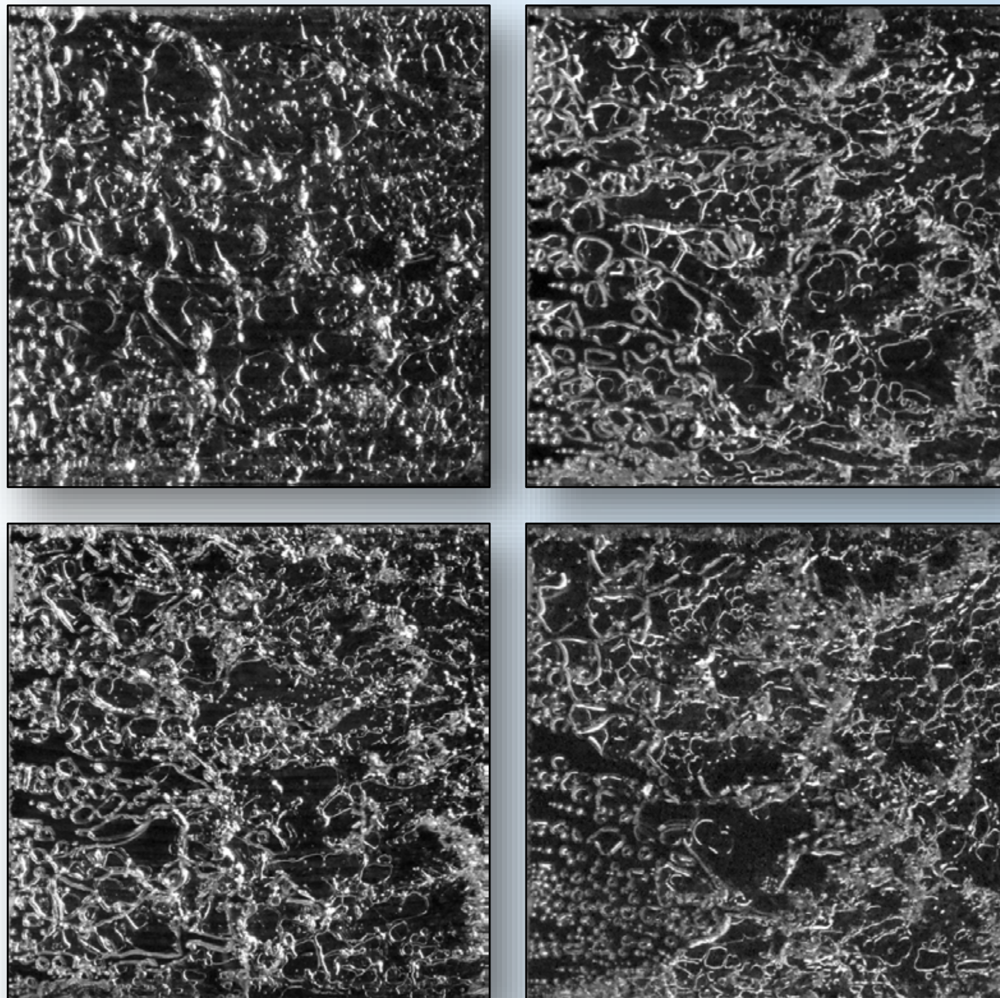
Orientation Independent Heat Transfer Coefficients (HTC)



Excellent agreement of HTCs across five orientations at three mass fluxes from 349.1 to 853.5 kg/m^2-s

Flow Visualization

218 µm
20 W/cm^2
360 kg/m^2-s



Horizontal Up

Vertical Upflow

Horizontal Down

Vertical Downflow

Path Forward

- Channel heights from 100 to 1000 μm over a range of mass fluxes from 100 to 1000 kg/m^2-s (or higher) to characterize g-independent operational range
- Microgravity validation of ground test results
  - Recently awarded suborbital flight opportunity by NASA Headquarters
- Stacked heated design to simulate 3D IC

Thermal Coatings Technology
Mark Hasegawa – Coatings Group Leader

- Materials Development
  - Molecular Adsorber Status (JWST, GEDI, ICON) (2 Patents Pending)
  - Lotus – Super-hydrophobic Coating Status (1 Patent Pending)
  - Goddard Composite Coating Variants (LCRD, SSPD, SS/Loral) (NTR)
  - SBIR-II AMSENG Next Generation White Radiator Spray Coatings
  - SBIR-II Triton System Variable Emittance Coatings
  - Black, Highly Diffuse Sprayable Coatings (OSIRIS-REx) (1 Patent Pending)
  - ITO/$InOH_3$ on dielectrics for charge dissipation (SSPD)

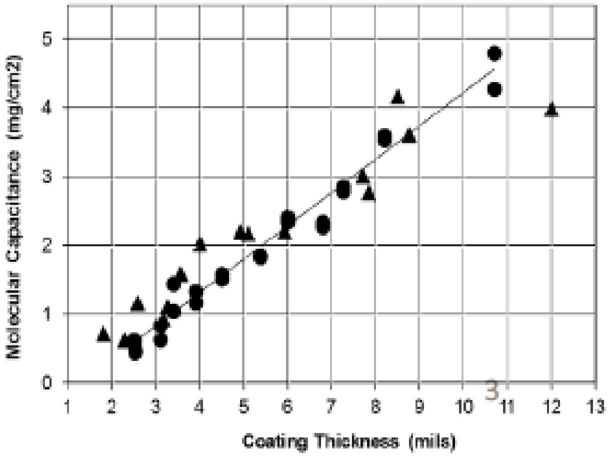
- Process Development
  - Oxygen Plasma Enhancement for Adhesion Improvement (SPP)
  - Outdated Silver Teflon Refurbishment
  - Reduced Particle Generation from Silicate Coatings (LCRD)
  - Stress Characterization in Silicate Coatings from Vacuum

Molecular Adsorber Coating (MAC)

POC: Nithin Abraham (ext 4-7070)

- White and Black in color, zeolite based system (Patent pending)
- Applied to rigid (aluminum) or flexible (Neptape) substrates
- On ICON and GEDI hardware for contamination control of molecular outgassed products
- Used in JSC Chamber A as a DP oil getter for JWST tests
- Currently considered for MARS2020 (significant testing-JPL)
- Considered for use on terrestrial systems (SPO Office)
  - Optical cavities for Giant Magellan Telescope in Chile (Black MAC)
  - Storage cabinets at National Museum of Natural History, Smithsonian Institution (White MAC)



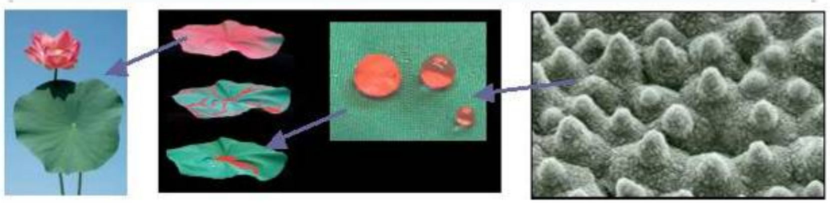



Lotus Dust Mitigation Coating

Mark Hasegawa/546

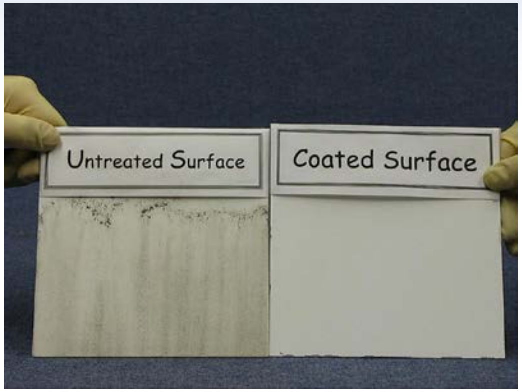
TECHNOLOGY/CAPABILITY AND IMPORTANCE

- The Lotus dust mitigation coating is a passive method for addressing Lunar and Martian dust accumulation concerns
- Microstructure effects and surface chemistry prevent accumulation of surface contaminants
- Based on observed properties of the Lotus plant



APPROACH

The Lotus coating sheds dust particles utilizing anti-contamination and self-cleaning properties that minimize dust accumulation on spacecraft surfaces. This coating sheds dust particles by reducing the surface energy and the amount of surface area available for attachment



Uncoated radaitator surface and Lotus Coated surface after exposure to JSC-1 Lunar Simulant

CAPABILITY STATUS, PLANS KEY CONTACTS

- GSFC has demonstrated this effect on standard AZ93P radiator paint;
- Surface contaminated with lunar simulant demonstrated less change in absorptivity than non-treated control sample
- Industry has expressed an interest in the technology

Electro-hydrodynamic (EHD) Technology Development

High Heat Flux, High Temperature Heat Acquisition

Jeffrey R. Didion
Senior Thermal Engineer
Manager, Nanotechnology Facility

– Details can be found in Jeff’s Presentation

SUMMARY

- New Technology program underway at NASA, although funding is limited.
- NASA/GSFC's primary mission of science satellite development is healthy overall, new missions are in work – however impact of new administration in TBD
- Future mission applications promise to be thermally challenging
- Direct technology funding is still very restricted
  - Projects are the best source for direct application of technology
  - SBIR thermal subtopic continued in FY 17
  - Limited Technology development underway via IRAD, NESC, other sources